

Design Report for Doubly-Fed Induction Generator Test Bed

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Abstract: This report documents the design process used to develop a test bed for a doubly-fed induction generator to fulfill the requirements of the client, Normann Fischer of Schweitzer Engineering Laboratories, Inc. The intent is to convey the work that has been accomplished and justify the design choices that were made. This project was conducted to fulfill in part the requirements of the University of Idaho senior design capstone curriculum.

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May 10, 2013

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ATTN: Normann Fischer
Subject: Doubly Fed Induction Generator Test Bed

Enclosed is our final design report for the doubly-fed induction generator test bed.

At the conclusion of our time working on this project, we have designed and fully assembled the test bed system as well as completed some of the programming required to control the DFIG. Our deliverables consist of a motor and generator setup mounted to a steel frame, a power electronics cart, and an adjustable speed drive cart. The sensor array that comes with this setup includes a torque transducer, position encoder, and current and voltage transducers. The power electronics cart includes two IGBT modules, a DC chopper, three SCR modules, the driver boards for the previous items, and a bank of power resistors.

Testing has been performed on the adjustable speed drive, the DFIG, and the space vector modulation algorithm. In the ASD test, the adjustable speed drive successfully ran the SCIM and the alignment of the machines' shafts was verified. The DFIG's ability to generate power was tested and verified by applying a variable frequency voltage and current to the rotor using a synchronous generator with speed controlled by a DC machine.

The field oriented control algorithm required to control the DFIG is not fully implemented at this time, though we have most of the code required for this. An algorithm for open-loop space vector modulation has been tested but still requires adjustment in order to successfully control the switches. The remaining work required to implement the full algorithm consists of coding to read sensors as well verifying correct implementation of the space vector modulation

We would like to thank you for your support and sponsorship. Without a sponsor it would not have been possible to realize this project. Your investment of time and money into this project is deeply appreciated.

Sincerely,
DFIG Engineering

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Executive Summary

Schweitzer Engineering Laboratories, Inc. is interested in the construction of a test bed for a doubly-fed induction generator (DFIG or wound rotor induction machine). Our team has been tasked with designing and constructing such a setup. Their current understanding of how a DFIG acts during faults does not explain the behavior that they have observed during actual faults in the power distribution networks that they monitor. The test bed that we develop needs to be able provide a way to investigate how doubly-fed induction generators affect power and protection systems as well as verify software models currently being used by our client. With this knowledge in hand, Schweitzer Engineering Laboratories will be better able to design and produce relays and other protective equipment for power distribution networks that include DFIGs. Our secondary client, the University of Idaho (U of I), also needs the device to be compatible with their existing power labs, modular, and adaptable for future applications.

The solution that we have developed employs components purchased from manufacturers alongside components that were designed to provide the physical framework for the test apparatus. These parts will be installed in the University of Idaho's Analog Model Power System (AMPS) lab, which will provide the conditions under which the DFIG can be tested. Through our selection of the purchased components, we were able to create a system that will supply our client with torque, current, and voltage measurements from the DFIG that occurred during operation. According to our design, the power electronics on the rotor side of the DFIG will makes it possible for different control algorithms to be implemented. These two features will enable our client to develop their understanding of DFIGs through experimentation under different fault conditions as well as with different control algorithms. At this point, the components have been purchased and assembled. Some testing of the machines, sensors, and IGBTs has been conducted.

1 Background

Increases in the cost of energy and paradigm shifts in societal priorities have led to a higher demand for energies produced without the use of fossil fuels. One such technology that fills this niche is the wind turbine. Due to the stochastic nature of wind speeds, doubly-fed induction generators (DFIGs) are often used to convert the mechanical power of the wind to electrical power. The reasoning behind this is that these types of generators can handle a wider range of shaft speeds while outputting a fixed power system frequency. Furthermore, the size of the power electronics used to control the DFIG can be reduced because the power electronics do not need to handle the full armature power. However, less is known about the behavior of DFIGs during abnormal conditions compared to conventional induction machines.

The motivation for this project comes from our client Normann Fischer, who needs to know more about how DFIGs operate during fault conditions in order to design protective equipment and systems for wind turbine farms. The benefits of this system are that it will allow engineers to work in a laboratory setting to investigate how DFIGs react during faults, affect power and protection systems, investigate different load flow conditions, and verify software models currently in use. Engineers will be able to run simulations to see how different operating and power system conditions affect fault response. The knowledge gained from tests performed with this system can lead to improvements in wind turbine technology.

2 Problem Definition

The stakeholders of this project are interested in learning how to better protect these types of systems against power system instabilities such as faults. Therefore, it is the goal of this project is to design and construct a doubly fed induction generator test bed system, which can be used to help engineers and students learn more about the operation of wind turbines.

The specifications that we received from our client, were that the system is to use a 7.5 to 10 HP, and 1200 to 1800 RPM doubly fed induction generator and be run using the Analog Model Power System (AMPS) infrastructure provided by the University of Idaho. Wind conditions are to be simulated with a

squirrel cage induction motor (SCIM) controlled with an adjustable speed drive (ASD) and connected to the shaft of the DFIG. Furthermore, the system is to be designed such that the control of the DFIG can be determined by the user. In addition to this, the system is to have all of the sensors necessary to control and evaluate the behavior of the DFIG.

From what our client told us, we were able to develop a block diagram of the system that we wanted to create, which is shown below in Figure 1. The process for designing and selecting components for this system are discussed in sections 4 and 5. More information on the protective circuits (crowbar and DC chopper) can be found in section 4.5. Discussion of the power and information flows in this diagram follows in section 6.

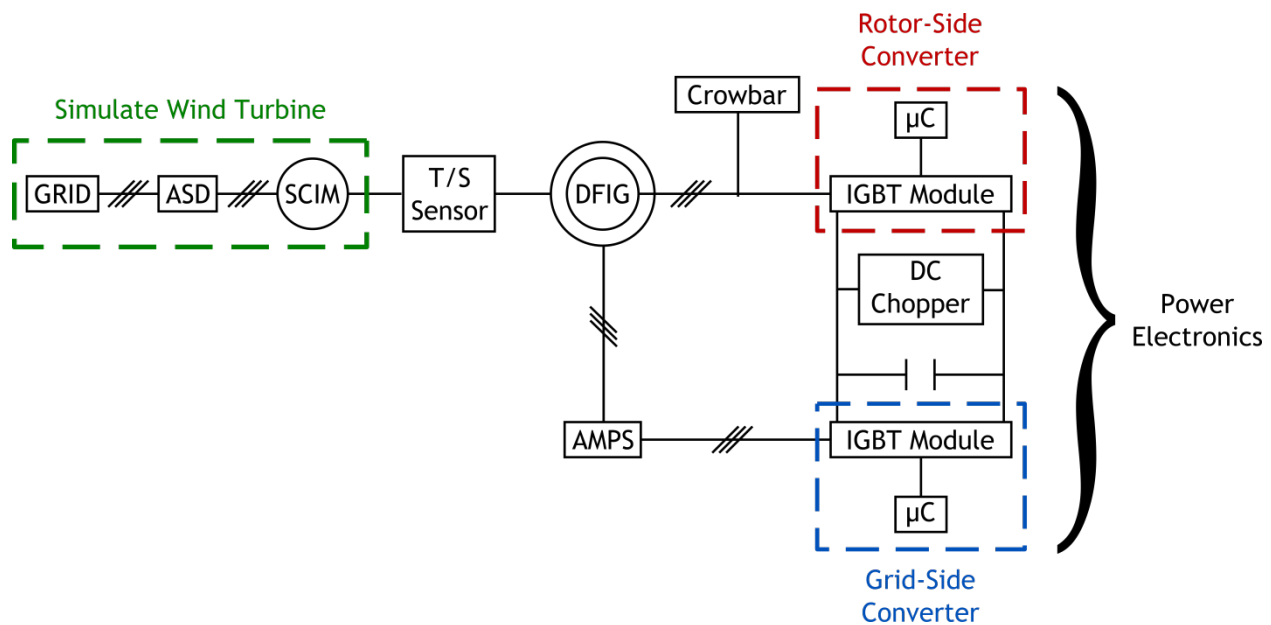


Figure 1. Block diagram of test bed setup for DFIG.

Our ultimate goal for this project was to have the test bed system fully operational with the microcontrollers that govern the power and DFIG-rotor-side converters programmed with a control scheme.

3 Project Plan

3.1 Responsibilities

As there were only three members on this team, most of the responsibilities were shared. However, certain members were delegated specific tasks. John Feusi's main tasks were mechanical component design and maintaining the project schedule and accounts. Wes Matej's specific responsibilities included the electrical component design and assembling team meeting presentations. The programming and implementation of the microcontrollers fell under the Carlos Solis's responsibilities. Shared responsibilities include research, overall system design, specifying and procuring parts, testing and assembling purchased equipment, maintaining records of work accomplished, and completing the coursework requirements.

3.2 Schedule

The main goals for the fall semester were to have all of the main components selected, purchased and assembled. The original schedule is shown below in Figure 2. Unfortunately, we were unable to meet these deadlines. By the end of the fall semester, we had purchased most of the major components including the AC motor, the wound-rotor induction machine, the adjustable speed drive, the IGBT modules, and the frame. However, the assembly of components had not been initiated by the end of the fall semester.

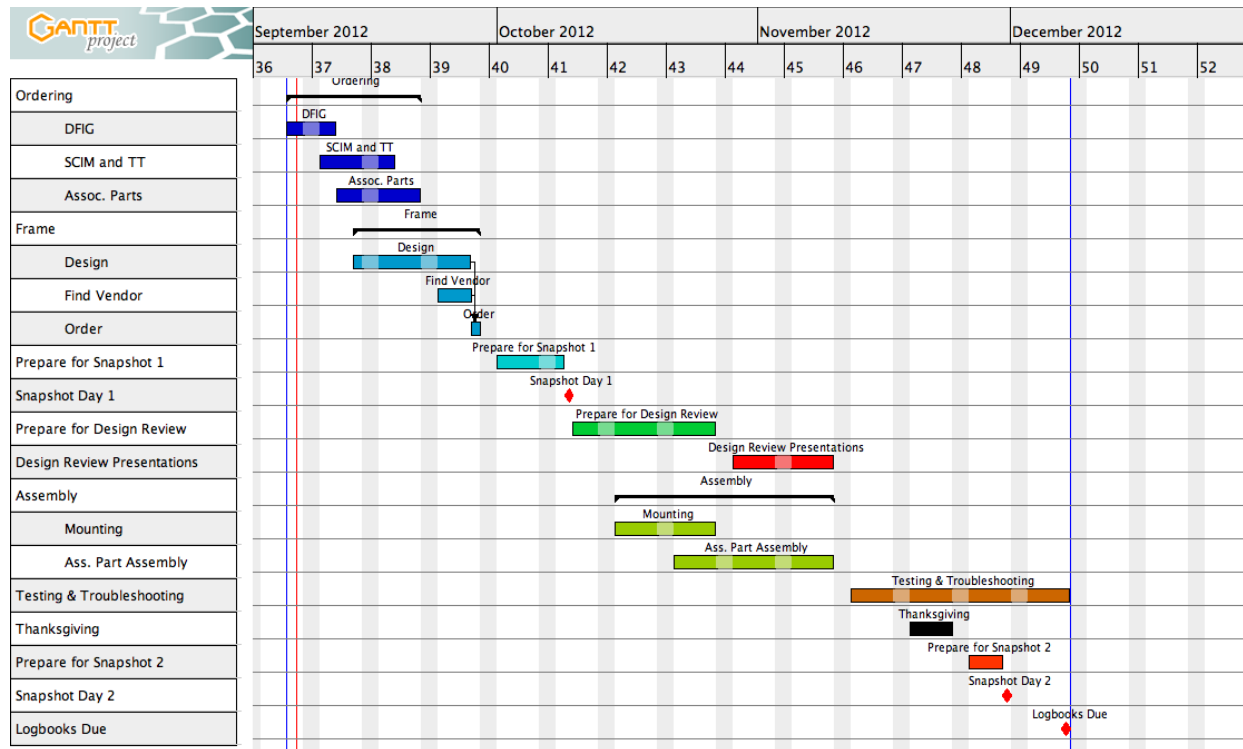


Figure 2. Project schedule created at the beginning semester.

For the spring semester, we picked up where we had left off at the end of the fall starting with the mounting of the motor-generator pair. We had still hoped to meet our ultimate goals for this project. We set out another schedule for the spring semester with which we would be able to achieve this end. The schedule can be seen below in Figure 3. While we were able to accomplish much of the work we were unable to meet all of our goals. The objectives that we were unable to hit included wiring for the DC power supplies and microcontrollers, as well as implementing field oriented control. However, even without these items, we were still able to give SEL the deliverables they desired. These items will provide opportunity for future work.

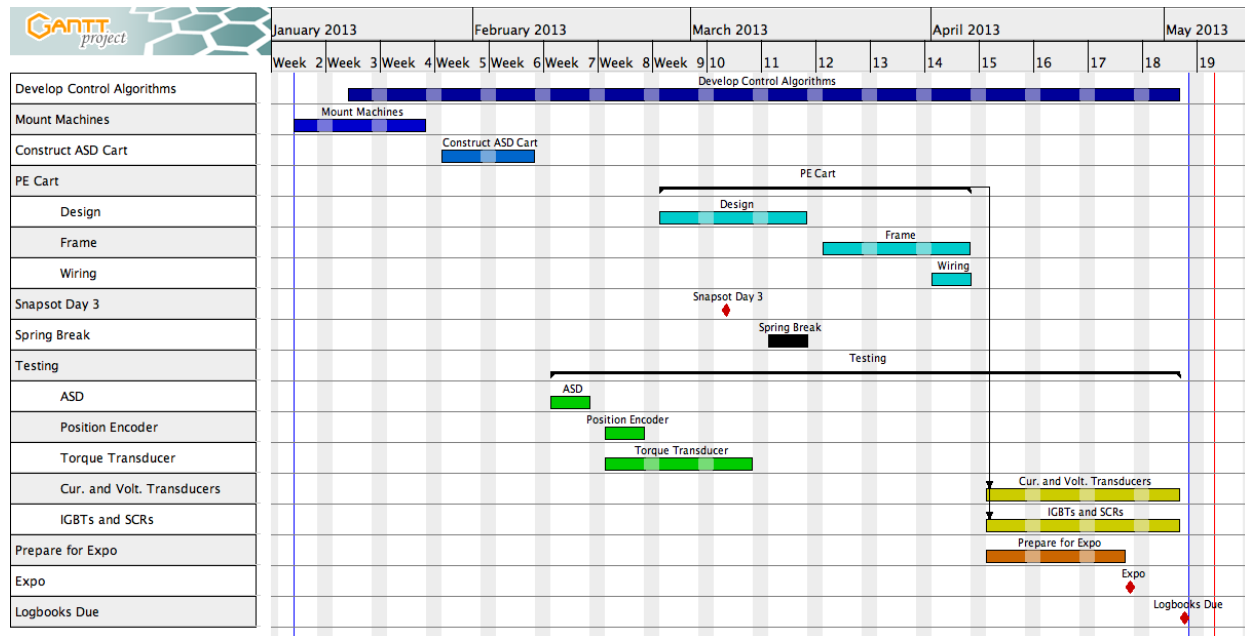


Figure 3. Project schedule created for the second semester

4 Concepts Considered

4.1 Induction Machines

The item in our system design that was most difficult to obtain was the doubly-fed induction generator. Knowing this, our conceptual design process started with this part. In consideration for the DFIG, our choice was governed by our rating specifications and by price. Our specifications were that the generator needed to be rated between 7.5-10 HP and 1200-1800 RPM. The goal was to procure a generator in this range for the best price. After sorting through many different used and new generators, our choices were narrowed down to a used, 10 HP Louis Allis, as well as machines made by Reuland and Doug Beat.

The SCIM was considered next after the selection of the DFIG. It was to be chosen with ratings compatible with the DFIG and purchased new off the shelf. Also, we wanted to try to purchase the SCIM and the adjustable speed drive (ASD) together as a package to ensure that they were compatible. An important requirement for the ASD was that it allowed for control of speed and torque independently. We explored several options and narrowed it down to two that met our requirements, which were an ABB ACS550 drive matched with a Baldor SCIM, and a Toshiba ASD and SCIM.

4.2 Mechanical Framework

Once the generator and motor were chosen, it was time to design the frame onto which they would be mounted. The concepts that were considered for the design of the frame can be broken down into two main groups: structure and mounting. The structure is the pieces that are welded together in a rectangle and provide the skeleton. For the structure the main options that were investigated were wide-flange I-beams, C-channels, or roll-formed solutions. The latter two of these possibilities were found in the existing power lab at the University of Idaho. The options considered for mounting were a bolt-driven system, welded blocks, bolted on blocks, or mounting directly onto the structure. The bolt-driven system came as a suggestion from our client. We also found examples of adjustable motor mounting bases from distributors.

Since we were not designing the couplers, the options that we had were limited but straight forward. The three types of couplings that we considered purchasing were curved jaw, disc, and bushed type sleeve couplings. The jaw type couplings had been used previously at the University of Idaho with a great deal of success. However, they have a large amount of backlash which was unacceptable so they could be immediately disregarded.

For our considerations in choosing wheeled carts for the ASD and power electronics, we wanted to minimize time spent constructing the carts. We also wanted the adjustable speed drive mounted on its own cart so that it could later be used separately from this project for other machines. Different options in construction methods and materials were considered. We observed electronics carts from previous projects that were located in the Gauss Johnson power lab for ideas. The engineering department had available spare Unistrut® strut channels, which provide a versatile medium. We also browsed catalogs of equipment distributors to garner other options.

Design of the cart for the power electronics followed a similar path. One important consideration that had to be taken into account that was less of an issue for the ASD, is that the microcontrollers needed to be shielded from electromagnetic radiation emanating from the IGBT modules. Also, much more space

was needed for all of the power electronic equipment. We had the same construction options available to make the power electronics cart as we did for the ASD cart.

In order to make our system flexible, we had to make sure our electrical connections would be compatible with both the power lab tables in the university's Gauss Johnson Power Lab and also with the Analog Model Power System (AMPS) Lab in the Buchanan Engineering Lab when considering the choices for our connection scheme, cables, and connectors,. The power lab tables use specially manufactured taperfit connectors and the AMPS lab uses 25A SUPERCON® connections. The engineering department has available taperfit to 25A SUPERCON® adapters. It is desired for the ASD to be compatible with other machines in the power labs that use taperfit connections.

4.3 Sensors

The first sensor that we set about selecting was the torque transducer because they are commonly more expensive and have longer lead times. In order to search for torque meters that would be feasible, we first had to determine the minimum torque rating. Using our nominal operating conditions determined by the DFIG, which are 10 HP and 1800 RPM, we were able to calculate the resulting shaft torque which was 350.1 in-lbf. This, and other calculations can be found in Appendix B. Using a safety factor of 3 meant that we needed a torque transducer with an operating torque of roughly 1000 in-lbf. Using this criteria, we narrowed our options down to three different models. These models were the Himmelstein MCRT 48202V(1-3)NA, the Interface® T5-15-B3A, and the Futek TRS605 FSH02058.

We began our process of choosing a position encoder by first looking at the encoders used on the machines in the university's power lab in the Gauss Johnson building. All of the encoders on the lab's machines were purchased from BEI and had position measurement resolutions of 2160 cycles/turn. Different rotary incremental encoders offered by BEI were compared. Our options for choosing an encoder were divided into two categories: shafted encoders and hollow shaft encoders. Shafted encoders use a design that allows them to be placed on the end of a shaft. These were preferable due to more

reasonable pricing. Hollow shaft encoders have a design that enables it to be slid onto the shaft of which it is measuring the position.

For the current transducers, we first needed to determine where we would be measuring current and what the ratings of the transducers would need to be. The current ratings of the DFIG are 28A on the primary side and 32A on the rotor side. We decided LEM was a good company to purchase current transducers from, and we decided to go with a current transducer with a 100A rating to be safe.

4.4 Power Electronics

To control the DFIG, we must take 3-phase alternating current, convert it to direct current, and then convert it back to alternating current of a different frequency which is then supplied to the rotor windings. This is accomplished through the use of an AC/DC/AC converter which employs insulated gate bipolar transistors (IGBTs). For a single phase, two IGBTs are required to convert from AC to DC or vice-versa. This means that for the rotor side voltage converter two sets of six IGBTs are required. Because we wanted our system to be off the shelf as much as possible, we decided to use six-pack IGBT modules (one AC/DC) that came with gate driver circuits and were optically isolated to reduce noise. Finding products that matched this description was difficult. As a result we only found two viable options. One was the IAP100T120 from Applied Power Systems which included two six-pack IGBT modules with a DC-link between them, mounted on a heat sink with blowers. The other option we found was the PM100CL1A060 from Powerex, Inc. The PM100CL1A060 did not have the optical isolation itself but was sold in conjunction with the BP7B-LS which provides the optical isolation. A heat sink is also required for the IGBTs. Numerous different types including extruded, bonded fin, and forced convection heat sinks were available. The selection of the heat sink was dependent on the allowable thermal resistance for the IGBT module.

The DC link capacitor needed to be chosen at a voltage rating compatible with the DC link voltage. The DC link voltage was calculated to be approximately 350 V. The capacitance needed to be high enough to give us an acceptable value for voltage ripple. Calculations were made and different

capacitance values were compared with their resulting calculated voltage ripple. Deciding upon the capacitor involved weighing tradeoffs between voltage ripple, cost, and space. The capacitance can be increased to lower the voltage ripple, but the size of the capacitor as well as the price increases with the capacitance rating. Too large of a capacitor could make the power electronics too bulky. Also, if too much energy can be stored in the capacitor problems can arise. Another factor that influenced our decision was availability. The capacitors were offered in their standard values, and some capacitors had very high and prohibitive lead times up to 6 weeks. Price was a significant contributor to our choice as well, since these capacitors can reach upwards of \$400. Different capacitors from Cornell Dubilier and United Chemi-Con were compared.

For the microcontrollers that control the IGBTs, we needed to choose one that provided a sufficient number of inputs and outputs. Initially, we wanted to make sure the microcontroller had 6 PWM channels to control the IGBTs, but later decided this was not an important requirement since we could use a different method involving interrupts instead of the built-in signals. Our choice was also governed by the idea that we should choose a microcontroller that has a sufficient amount of library material written for it already. We compared microcontrollers from both Atmel® and PIC®.

4.5 Self-Protection Circuits

Due to the possibility of voltages and currents in the DFIG system exceeding system ratings and response to external disturbances, it was desired to implement into the system a method of system self-protection. Four different concepts commonly applied in the field were researched and considered for protection circuits. These were the passive rotor crowbar, active rotor crowbar, stator crowbar, and DC chopper. The passive rotor crowbar design consists of a bank of bypass resistors connected to the rotor windings by controllable switches. During activation, the generator rotor windings are short circuited through the crowbar circuit, and the rotor currents are limited accordingly to the crowbar resistor dimensioning.

The stator crowbar design is somewhat similar to the rotor crowbar, except that it would be located on the stator side of the machine. This design would be implemented with bidirectional switches and damping resistors connected in series with the stator. Activation of the crowbar would increase stator resistance and provide passive damping.

The DC chopper circuit design requires a bypass resistor and controllable switch placed in parallel with the DC bus capacitor. During activation, the switch is closed and the DC bus voltage and current is limited accordingly to the resistor dimensioning.

5 Concept Selection

5.1 Critical Components

Our decision for which doubly-fed induction generator to choose was based mostly on price, as all of our narrowed down options would have fit our criteria and there was little difference in terms of expected performance. The used Louis Allis was available for \$750. Although we were still required to get an overhaul for \$500, a significant amount of money was saved when compared with the other choices.

We chose to go with the Baldor EM3714T motor and ABB ACS-550-U1-031A-2 because they met all of our specifications and were available at a lesser price than the Toshiba motor and Toshiba ASD. Cost was also a factor in choosing the ACS-550-U1-031A-2 over the ACS-800-U1-0011-2+P901. The 550 model provided all the features that we needed (independent torque and speed control) at a much lower cost.

In selecting the frame, we quickly ruled out using a design that was roll-formed. A roll-formed solution would have been weaker and more difficult to manufacture. From there, we decided to use the I-beams over the C-channels. Since the frame will only be moved a few times in its lifespan, the additional weight of the I-beam is an irrelevant point. Also, this additional weight adds more strength to the structure. The other reason that we went with I-beams rather than C-channels is that the I-beams are flat on both sides whereas the C-channels are not. The fact that the C-channel is not flat on both sides creates

additional problems when bolting the mounting mechanism onto the C-channels. The mounting option that we decided to go with was bolt-on blocks. Welded blocks would not have given the adaptability that we want to provide. Purchasing a bolt-driven system would have made integrating with the structure of the frame difficult because the generator and motor are different frame sizes and fabricating our own bolt-driven system would have been complicated and costly in terms of time. Mounting directly to the structure would have been the cheapest and simplest but would not have had enough clearance to allow for our shaft alignment tool. A drawing of the frame and mounting system can be seen directly below.

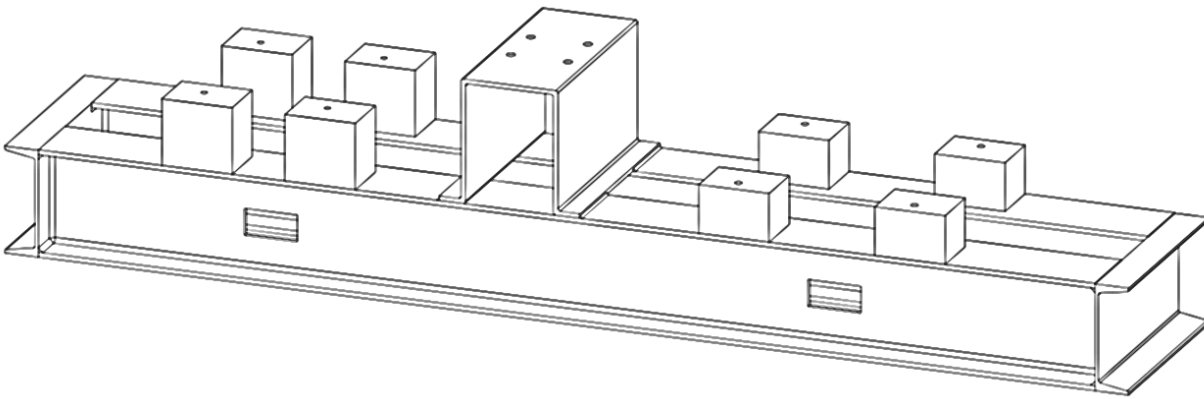


Figure 4. Frame with mounting blocks attached. I-beams run the length of the frame and the ends are capped with C-channels. Square cutouts in I-beams allow for the use of straps in hoisting the frame assembly.

Selection of the couplings was simple. Since the jaw type couplings were eliminated quickly as previously mentioned, our two options were disc and bushed type sleeve couplings. The disc couplings were designed to handle both axial and angular misalignment. However, they require much more space. The other advantage that the bushed type sleeve coupling has is that it is much less expensive.

5.2 Portable Components

We decided to use the Unistrut® to fabricate a cart for the ASD and purchase a dolly onto which we can mount a platform for the power electronics. This way we were able to easily and quickly manufacture the cart while taking advantage of surplus goods. For the power electronics cart, we decided

to purchase a wooden dolly on which we could build a Unistrut® frame. We decided to go with the dolly because it would provide additional mounting space which was not an issue for the ASD cart. Steel panels would be mounted onto the frame which would create a place to attach electronics to as well as provide electromagnetic shielding. Plexiglas panels were mounted on either side to create panels for which the SUPERCON® receptacles could be attached. By using Plexiglas instead of steel like the rest of the cart, we were able to tap holes directly into it which was useful for mounting printed circuit boards.

When deciding upon our connection scheme, cables and connectors, we decided to use taperfit connections for the input and 25A SUPERCON® connections for the output of the ASD drive. This gives the ASD good compatibility with other university machines and also compatibility with the AMPS power lab. Safety is always a concern when working with electrical equipment. To prevent injury to a person and/or damage to the equipment we decided to use different connections for the input and output of the ASD drive. This will make it difficult for a user to accidentally switch the input and output connections. For the power electronics cart, all the connections are SUPERCON® because they are more convenient to work with.. Connecting the DFIG is a more involved process and so it is less likely that someone will interchange the grid and rotor side without thinking.

5.3 Sensors

When making our final decision for the torque transducer, we chose the Himmelstein MCRT 48202V(1-3). Our rationale was that it was the cheapest while providing both analog and digital outputs. Furthermore, it comes with a software package to support its operation.

We were limited in our selection of the position encoder. Originally we had wanted to use a shafted encoder due to their relatively cheap cost. However, after we selected the doubly-fed induction generator we contacted the vendor to determine whether or not the DFIG had an opposite drive end shaft. We were informed that it did not and were supplied with photographs. From our inspection of the photographs we concluded that using a shafted encoder would not be viable. From there we chose the HS45 because it was the only hollow shaft encoder model available that was compatible with the larger

1.375 in shaft diameter of the DFIG. We also decided to go with 8192 counts per revolution because it was inexpensive (\$25) to upgrade to this resolution.

5.4 Power Electronics

The IGBT modules are the most sensitive parts in our design. Should there be an error or a miscalculation, it is likely that it would cause irreparable damage to the IGBT modules. This played a large role in influencing our decision for which part to choose. The quote we received for the IAP100T120 from Applied Power Systems was for \$5,250. Furthermore, they were unwilling to supply us with pricing information for the individual components that makeup the IAP100T120. Using the Powerex PM100CLA060, on the other hand, we were able to purchase all of the required parts including spares for under \$2,400. Another distinct advantage of using the Powerex IGBT modules is that should we damage them and then decide that we need a higher current rating, it will be cheap to purchase the higher rated modules because all of the other components can still be used. Some considerations other than price that we took into account were the fact that the APS module had over current protection and over voltage protection (disadvantage because it limits what we can investigate, but good because it adds protection of the equipment), and the fact that the Powerex would require more assembly and component selection. Taking all of this into consideration, we decided to go with the PM100CLA060.

With the IGBT module selected, we could then select a heat sink. Using information from the IGBT module datasheet we were able to calculate the maximum allowable thermal resistance for the heat sink. See appendix B for more details. Based off of our calculations we determined that we needed a heat sink with a thermal resistance of no more than 0.09 °C/W. The recommended heat sink for our module was the CH5116 from C&H Technology. This recommendation was corroborated by our calculations.

When making a decision on the selection of a DC link capacitor several capacitors were compared from Cornell Dubilier and United Chemi Con. With voltage ripple calculations, it was decided that a capacitance value around 3000uF or higher would be suitable. The options available at Cornell Dubilier were very expensive and it was found that United Chemi Con was willing to give us samples for

free, so our team decided to choose a United Chemi Con capacitor. We were able to obtain two 4700uF sample capacitors rated for 400V.

5.5 Self-Protection Circuits

After review and research of the four considered concepts for power electronics protection circuits, a decision was made to implement both the DC bus chopper and the passive rotor crowbar. Although only one form of protection circuit is needed, the two circuits were included for the purpose of comparing their operation. The protection circuits we chose were two of the more common designs used by industry because the ultimate purpose of this project is to investigate the effects on power transmission protection systems due to external faults interacting with a DFIG. This way, we will be able to see how the DFIG would respond to the disturbances with the different self-protection schemes.

6 System Architecture

The system that we developed consists of three main components: the adjustable speed drive cart, the motor-generator pair mounted on the frame, and the power electronics cart. These components are displayed below in Figure 5. These components are the deliverables that we will be able to give SEL.

The frame of the test bed provides a platform to which the DFIG, SCIM, and torque transducer can be mounted. This makes it possible to align the shafts and keep the motors rigid during operation. It is constructed out of two 5 ft W 6x12 beams with C 6x8.2 channels welded on both ends. On the top in the middle is a 1/4 in roll-formed piece of steel that provides a platform on which to mount the torque transducer. Most of the design of the frame was drawn from previous work done at the University of Idaho. However, one feature that sets it apart from the rest is the mounting blocks. The mounting blocks are steel blocks with bolt holes tapped into the bottom and top. These blocks are bolted onto the wide flange beams and then the motor is mounted onto the blocks. Previous designs had welded the mounting blocks onto the base. Our design has two main advantages. One, it makes the task of alignment easier because without the welding, there is less deformation. Second, it allows for more flexibility. Should

there be an issue with the manufacture of the frame or mounting blocks, our design makes it possible to remove the mounting blocks and re-machine them. It also makes using different motors a feasible option.

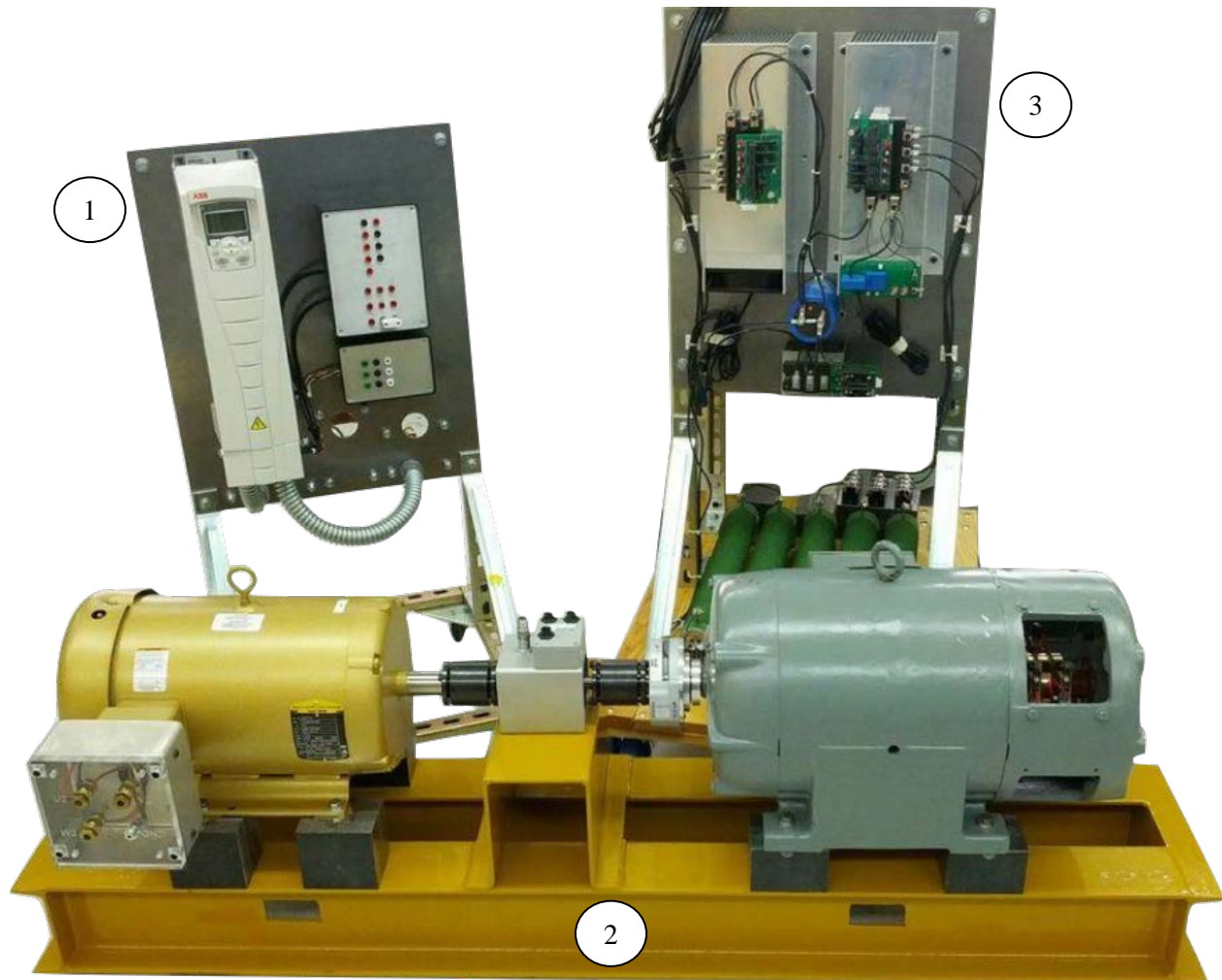


Figure 5. Test bed system for DFIG. 1-ASD Cart, 2-Frame, 3-Power Electronics Cart. The machine on the left is the SCIM and on the right is the wound rotor induction machine.

The ABB ACS-550-U1-031A-02 adjustable speed drive provides a way to power and control the SCIM. One feature of the ASD that we chose is that it allows for the control of speed and torque independently. It comes with several pre-programmed and customizable application macros for different operation schemes to minimize setup time. The motor-generator set consist of a Baldor EM3714T SCIM as the prime mover, and a Louis Allis wound rotor induction machine. The DFIG is rated for 10-HP and 1750-RPM. The SCIM is rated for 10-HP and 1770-RPM.

The shaft-to-shaft torque transducer is a Himmelstein MCRT 48202V(1-3)NA. It is the piece that physically transmits the mechanical input from the SCIM into the DFIG. The purpose that it serves is to enable our client to take measurements of the torque that is being input to the DFIG. The measurement of torque is an important part because the mechanical torque being put on the generator is used in both the control and modeling of the DFIG. Without this measurement, there is not enough information for our client to verify the models that they have in place. The torque transducer also has a speed pickup which could possibly be used by the ASD or other testing purposes. On either shaft of the torque transducer is one of the bushed type sleeve couplings. These couplings provide the mechanical link between the shafts of the torque transducer and the shafts of the induction machines.

The BEI HS45 rotary incremental encoder is a hollow shaft encoder that mounts directly to the shaft and is held in place by an arm that mounts to the frame of the test bed. It has the purpose of taking a mechanical reading from the shaft, encoding it, and outputting a digital quadrature output that conveys the speed and position of the shaft. It also allows for the option of sending the signal differentially to reject more signal noise and obtain a more accurate, cleaner signal and better performance. It has a very high resolution of 8192 cycles per turn. The signal from this device is fed into the microcontroller that controls the power electronics on the rotor side of the DFIG.

Two Microchip Explorer-16 development boards, with dsPIC33FJ256MC710A microcontroller plug-in-modules, are used to control the power electronics on the rotor side of the DFIG as well as record data taken during experimentation. The microcontrollers interface with the IGBT modules, current and voltage transducers, and the position encoder during normal operation. Powerex BP7B-LS boards provide optical isolation between the microcontrollers and the IGBT modules. A third Explorer 16 development board is used to control the two self-protection circuits.

The power electronics on the rotor side of the DFIG consist of Powerex PM100CLA060 IGBT modules with built-in gate driver circuits and a 4700-uF United Chemi-Con capacitor for the DC-link between converters. The circuits that provide protection for the power electronics are the rotor crowbar and DC chopper. The rotor crowbar consists of three TE Connectivity 100 Ω , 2 kW wire wound resistors

that can be connected across the lines of the rotor through the use of MCC162-16IO1 IXYS SCR modules. The SCR modules' switching is performed by an ENERPRO FCOAUX60 firing board.

7 Testing

At the conclusion of our time on this project, the system has been assembled and testing has been performed on the ASD, both induction machines, the position encoder, the torque transducer and a space vector modulation algorithm. Testing the ASD and induction machines consisted of using the ASD to drive the SCIM at a range of speeds from 0 to 1770 RPM. While running the SCIM we were also able to test the wound rotor machine and the position encoder. The wound rotor's ability to generate power was tested and verified by applying a variable frequency voltage and current to the rotor using a synchronous generator with speed controlled by a DC machine. For the position encoder we verified that we were getting pulses on each of the six outputs. A static test was also performed to verify that the torque transducer would output analog measurements which was successful. However, tests were only performed to approximately 20 in-lbf. With the space vector modulation algorithm we were able to successfully generate PWM signals, but the signals as they are now still need to be inverted in order for them to successfully control the IGBTs. The signals that we were able to generate can be seen below in Figure 6.

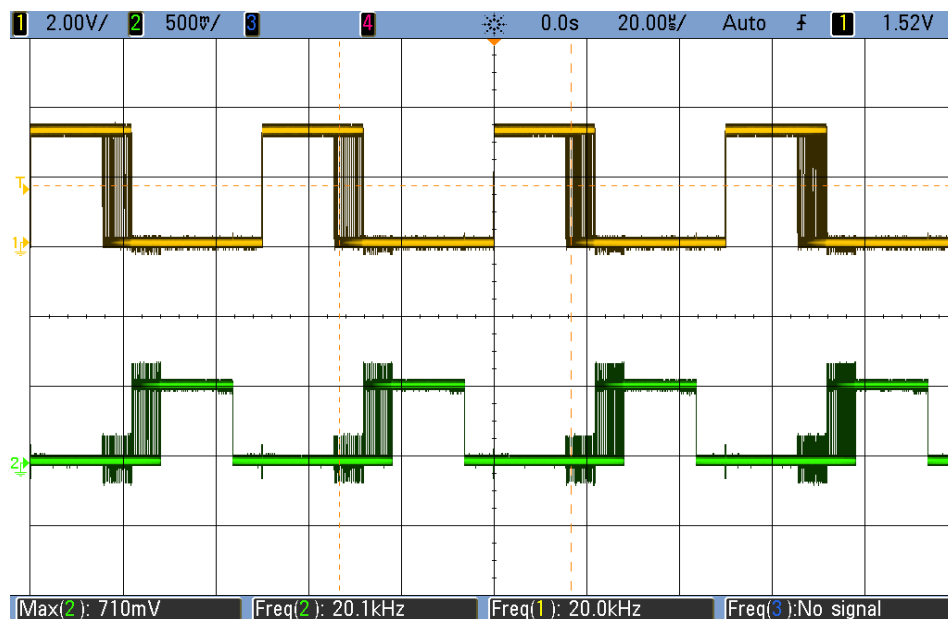


Figure 6. PWM signals generated for high and low gate of one leg.

8 Future Work

There are still additional items that need to be completed. These items are left as work for future teams. They include:

- 1) Connecting DC power supplies to sensors
- 2) Connecting microcontrollers to gate drivers, the SCR firing board, and sensors
- 3) Verification of current and voltage sensors readings
- 4) Calibrations of sensors
 - a) Current
 - b) Voltage
 - c) Torque
- 5) Coding
 - a) Invert PWM signals
 - b) Field-Oriented Control
 - c) Read outputs from current, voltage, torque, and position sensors
- 6) Verification of gate driver board and IGBT module switching
- 7) Verification of self-protection circuit performance

9 Summary

This report discussed the development of a test bed system for a doubly-fed induction generator. It was designed as part of the curriculum for the engineering senior design capstone project at the University of Idaho. The system consists of an adjustable speed drive, squirrel cage induction machine, torque transducer, position encoder, wound rotor induction machine, back-to-back IGBT modules, a DC chopper, and a rotor crowbar. The system was designed for power transmission protection engineers at Schweitzer Engineering Laboratories and can be used to test effects on power transmission protection systems due to interactions between external grid faults and a DFIG. The DFIG Engineering team would like to thank their advisors Drs. Joe Law and Brian Johnson, as well as the support from U of I faculty

and staff including Drs. Herb Hess and Richard Wall, Greg Klemesrud, and Russ Porter. The team would also like to thank SEL for their generous support, especially Normann Fischer. Without the backing of these people this project would not have been possible.

Appendices

Appendix A – Budget

Expenditures					
Date	Amount	Price	Shipping	Vendor	Description
10/18/2012	\$1,750.00	\$1,350.00	\$400.00	Power Equipment Co.	Louis-Allis Motor
10/18/2012	\$135.30	\$127.90	\$7.40	Digi-Key Corp.	Current Sensors
10/18/2012	\$1,291.03	\$1,255.80	\$35.23	State Motor & Control	ASD
10/18/2012	\$961.81	\$876.81	\$85.00	Priest Electric	Baldor Motor
10/22/2012	\$17.04	\$10.34	\$6.70	Digi-Key Corp.	BP7B Parts
10/22/2012	\$196.67	\$186.13	\$10.54	McGuire Bearing Co.	Couplers
10/24/2012	\$2,892.75	\$2,892.75	\$0.00	S. Himmelstein & Co.	Torque Transducer
10/30/2012	\$1,560.72	\$1,498.28	\$62.44	Powerex, Inc.	IGBT Modules
10/31/2012	\$394.15	\$380.08	\$14.07	Galco Electronics	Gate Driver Board
11/2/2012	\$172.50	\$148.50	\$24.00	McMaster-Carr	ASD Cart Hardware
11/5/2012	\$392.16	\$374.98	\$17.18	Microchip	Microcontrollers
11/14/2012	\$41.34	\$31.70	\$9.64	Arcade Electronics	Fans
11/14/2012	\$331.70	\$311.50	\$20.20	C&H Technology	Heat Sink
11/16/2012	\$1,101.00	\$1,101.00	\$0.00	BEI Industrial Encoders	Position Encoders
11/16/2012	\$82.69	\$64.60	\$18.09	C&H Distributors	Dolly
11/28/2012	\$91.35	\$84.04	\$7.31	Zero Manufacturing	Connector Box
12/5/2012	\$120.00	\$120.00	\$0.00	Precision Engraving	ASD Plates
12/12/2012	\$414.00	\$414.00	\$0.00	Mundy's Welding	Frame
1/11/2013	\$17.99	\$17.99	\$0.00	Radioshack	HDMI Cable
1/13/2013	\$357.74	\$325.42	\$32.32	McMaster-Carr	PE Cart Hardware
1/17/2013	\$545.74	\$535.09	\$10.65	Digi-Key Corp.	Volt. Transducers, etc.
1/17/2013	\$135.00	\$135.00	\$0.00	P&R Sandblasting	Painted Frame
1/24/2013	\$464.44	\$453.00	\$11.44	Digi-Key Corp.	TVS & Power Converter
1/24/2013	\$514.12	\$498.41	\$15.71	Galco Electronics	SCR, IGBT, Gate Drive
1/25/2013	\$854.28	\$854.28	\$0.00	UI Facilities	Motor Blocks
2/11/2013	\$13.30	\$13.30	\$0.00	UI Facilities	Conduit

2/13/2013	\$712.13	\$691.56	\$20.57	Digi-Key Corp.	Power Resistors
3/8/2013	\$192.02	\$181.45	\$10.57	Digi-Key Corp.	Power Supply, Cable
4/5/2013	\$695.00	\$695.00	\$0.00	Sunrise Electronics	PCBs
4/5/2013	\$76.52	\$76.52	\$0.00	Precision Engraving	PE and ASD Plates
4/9/2013	\$39.52	\$32.32	\$7.20	Digi-Key Corp.	Current Sensor
4/25/2013	\$81.49	\$81.49	\$0.00	Copy Center	Poster
TOTAL*		\$16,645.50			

*Additional shipping charge from facilities on motors

Received	
Date	Amount
10/17/2012	\$8,078.81
10/30/2012	\$5,077.07
1/30/2013	\$3,156.75
4/1/2013	\$927.76

Account Balance
\$594.89

Appendix B – Calculations

DC Link Capacitor Sizing

Determining the peak of the worst case AC inverter current:

$$V_{LL} = 0.612 \cdot m_a \cdot V_{dc} \quad (\text{Eq. 8-57 Mohan})$$

$$m_a := 0.8 \quad \text{amplitude modulation ratio, upper bounds}$$

$$V_{LL} := 170\text{V} \quad I_L := 32\text{A} \quad \text{on rotor side}$$

Determining the DC bus voltage:

$$V_{dc} := \frac{V_{LL}}{(0.612 \cdot m_a)} \quad \text{Using Mohan equation}$$

$$V_{dc} = 347.222\text{V}$$

Determining the max AC power

$$P := \sqrt{3} \cdot V_{LL} \cdot I_L \cdot 1 \quad \text{letting pf}=1$$

$$P = 9.422\text{-kW}$$

The peak of worst case AC inverter current:

$$i_c := \frac{P}{V_{dc}}$$

$$i_c = 27.136\text{A}$$

+

What value of voltage ripple do we want?

$$\Delta v := 0.6\text{V}$$

$$\Delta t := \left(\frac{1}{10000} \right) \text{s}$$

$$C_{dclink} := \frac{i_c}{\left(\frac{\Delta v}{\Delta t} \right)}$$

The resulting capacitance:

$$C_{dclink} = 4.523 \times 10^3 \cdot \mu\text{F}$$

Beginning with a capacitance value, what is the resulting calculated voltage ripple?

$$C_{dclink2} := 4700\mu\text{F}$$

$$(\Delta v2) := \frac{i_c \cdot \Delta t}{C_{dclink2}}$$

$$\Delta v2 = 0.577\text{V}$$

Capacitor Discharge Resistor Sizing

Plan:

1. Decide how fast to discharge the capacitor ($t_{\text{discharge}}$). Longer times will waste less power.
2. Calculate a value for the resistor so that the RC time constant is $2/3$ of $t_{\text{discharge}}$.
3. V^2/R will tell how much power I am wasting, and let me size the resistor.

$$t_{\text{discharge}} := 10\text{min} \quad C_{\text{dclink}} := 4700\mu\text{F} \quad V_{\text{dclink}} := 350\text{V} \quad V_{\text{dclinkhigh}} := 450\text{V}$$

$$\tau = R_{\text{discharge}} \cdot C_{\text{dclink}} = \left(\frac{2}{3}\right) \cdot t_{\text{discharge}}$$

$$R_{\text{discharge}} := \frac{\left[\left(\frac{2}{3}\right) \cdot t_{\text{discharge}}\right]}{C_{\text{dclink}}}$$

$$R_{\text{discharge}} = 85.106\text{-k}\Omega$$

$$P_{\text{loss}} := \frac{V_{\text{dclink}}^2}{R_{\text{discharge}}}$$

$$P_{\text{loss}} = 1.439\text{ W}$$

$$P_{\text{highvoltage}} := \frac{V_{\text{dclinkhigh}}^2}{R_{\text{discharge}}}$$

$$P_{\text{highvoltage}} = 2.379\text{ W}$$

$$R_{\text{choose}} := 100\text{k}\Omega$$

For chosen resistor:

$$P_{\text{loss2}} := \frac{V_{\text{dclinkhigh}}^2}{R_{\text{choose}}} = 2.025\text{ W}$$

+

$$t_{\text{discharge2}} := (R_{\text{choose}}) \cdot C_{\text{dclink}} \cdot \left(\frac{3}{2}\right) = 11.75\text{-min}$$

Heat Sink Sizing

Using nominal horsepower and voltage calculate the nominal current

$$I_{RMS} = HP \frac{745.7}{V_{RMS}}$$

Determine the peak current for the collector and emitter

$$I_{cp} = I_{ep} = \sqrt{2} I_{RMS}$$

IGBT and Diode losses are made up of two components: steady-state and switching

IGBT

$$P_{ss} = I_{cp} V_{ce,sat} \left(\frac{1}{8} + D \frac{\cos(\theta)}{3\pi} \right)$$

$$P_{sw} = \frac{f_{sw} (E_{sw,on} + E_{sw,off})}{pi}$$

Diode

$$P_{dc} = I_{ep} V_{ec} \left(\frac{1}{8} + \frac{D \cos(\theta)}{3\pi} \right)$$

$$P_{rr} = 0.125 I_{rr} T_{rr} V_{ce,pk} f_{sw}$$

The temperature of the case is then dictated by one of the two following equations

$$P_{ss} + P_{sw} = \frac{T_{j,IGBT} - T_c}{R_{jc,IGBT}}$$

$$P_{dc} + P_{rr} = \frac{T_{j,FWD} - T_c}{R_{jc,FWD}}$$

Then you can calculate the allowable thermal resistance for the heat sink

$$R_{sa} = \frac{T_c - T_a}{N(P_{ss} + P_{sw} + P_{dc} + P_{rr})}$$

Using the following values

$$HP = 10\text{hp} \quad V_{ce,sat} = 2.35\text{V} \quad D = 0.75 \quad \theta = 0\text{rad} \quad f_{sw} = 10\text{kHz}$$

$$E_{sw,on} = 5.5\text{mJ/pulse} \quad E_{sw,off} = 4.5\text{mJ/pulse} \quad V_{ec} = 3.3\text{V} \quad I_{rr} = 35\text{A} \quad T_{rr} = 0.25\mu\text{s}$$

$$V_{ce,pk} = 550\text{V} \quad R_{jc,IGBT} = 0.35^\circ\text{C/W} \quad R_{jc,FWD} = 0.56^\circ\text{C/W} \quad T_{j_IGBT} \text{ or } T_{j_IGBT} = 125^\circ\text{C}$$

$$T_a = 25^\circ\text{C}$$

We calculated that the maximum allowable thermal resistance of the heat sink was $R_{sa} = 0.09^\circ\text{C/W}$. For additional information on these calculations see Powerex's application note General Considerations: IGBT & IPM modules section 3.4. As of 5/19/2013 this information could be found at <http://www.pwr.com/pwr/app/IGBT-Intelligent-PwrMods.pdf>.

Appendix C – Datasheets and User's Manuals

The following list details all relevant datasheets and user's manuals associated with components purchased for this project. Hardcopies have been collected and brought together in a black three ring binder for reference use while in the lab. The binder is stored in the Gauss Johnson Junior Power Electronics Lab room GJ 102B along with the ASD and power electronics carts. When the project is transferred to the basement of the Buchanan Engineering Lab, the binder will be moved as well. The URL's included with these datasheets were accessed on 5/9/2013. Copies of these reference materials can also be found on the U of I engineering senior design website in the project archive section (<http://seniordesign.engr.uidaho.edu/archive.html>) or our individual team website (<http://seniordesign.engr.uidaho.edu/2012-2013/sel/index.html>)

- ABB Adjustable Speed Drive: ACS 550-01 Drives (1...200 hp) User's Manual
[http://www05.abb.com/global/scot/scot201.nsf/veritydisplay/87d21c000e17fc33c12575ef004f3107/\\$file/EN_ACS550_01_UM_G_A4_ScreenRes.pdf](http://www05.abb.com/global/scot/scot201.nsf/veritydisplay/87d21c000e17fc33c12575ef004f3107/$file/EN_ACS550_01_UM_G_A4_ScreenRes.pdf)
- Himmelstein Digital Torque Transducer: MCRT 48202V(1-3)NA
http://himmelstein.com/images/manuals/6dfda10183edMCRT_48200V_Digital_Torquemeter_Manual.pdf and <http://www.himmelstein.com/images/product-datasheets/25ad174381b0B7410.pdf>
- BEI HS45 Position Encoder: HS45F-137-R2-SS-8192-ABZC-28V/5-SM18
http://www.beiied.com/PDFs2/HS45_Incremental_Encoder.pdf
- Powerex IGBT Module: PM100CLA060 <http://www.pwr.com/pwr/docs/pm100cla060.pdf>
- Powerex Gate Driver Board: BP7B-LS
<http://www.pwr.com/pwr/docs/BP7B%20Application%20note.pdf>
- Powerex IGBT Module: CM100E3U-24H <http://www.pwr.com/pwr/docs/cm100e3u24h.pdf>
- Powerex Gate Driver Board: BG2B-5015 http://www.pwr.com/pwr/app/bg2b_application_note.pdf
- IXYS SCR Module: MCC 162-16-io1 <http://ixapps.ixys.com/DataSheet/L081.pdf>

- ENERPRO SCR Firing Board: FCOAUX60 <http://www.enerpro-inc.com/images/stories/enerpro/products/FCOAUX60/PD736-3.pdf>
- LEM Current Transducer: LA 100-P <http://www.lem.com/docs/products/la%20100-p%20e.pdf>
- LEM Voltage Transducer: LV 25-P <http://www.lem.com/docs/products/lv%2025-p.pdf>
- Power-One $\pm 15\text{V}$ DC Power Supply: HBB15-1.5AG <http://www.power-one.com/sites/power-one.com/files/documents/power/datasheet/lin.pdf>
- CU I Inc 36V DC Power Supply: VPU-S200-36 <http://www.cui.com/product/resource/vpu-s200-series.pdf>
- Microchip: Explorer 16 Development Board
<http://ww1.microchip.com/downloads/en/DeviceDoc/Explorer%2016%20User%20Guide%201589a.pdf>
- Microchip Microcontroller: dsPIC33FJ256MC710A
<http://ww1.microchip.com/downloads/en/DeviceDoc/70594d.pdf>. Additional references, user's manuals, data sheets, and information can be found at
<http://www.microchip.com/wwwproducts/Devices.aspx?dDocName=en546066#documentation>
- Baldor AC Motor: EM3714T
<http://www.baldor.com/support/Literature/Load.ashx/MN408?ManNumber=MN408>
- Louis-Allis wound rotor induction machine, 10hp, 220V, 28A, secondary: 170V, 32 A. No documentation was found.
- BlackStar Split Taper Bushing used with CSH coupling: <http://www.mcguirebearing.com/wp-content/uploads/2009/01/blackstar-bushings-web.pdf>
- Abbreviated startup procedure specific to use in our lab. See next page.

Objective

The objective of this handout is to safely walk through the procedure for connecting the ACS550-U1-031A-2 to an induction motor. This handout is intended to be a supplement to the User's Manual.

Equipment

- ACS550-U1-031A-2 and corresponding User's Manual
- 3 taper-fit to taper-fit jumpers
- 3 SUPERCON® to SUPERCON® jumpers
- 1 SUPERCON® to taper-fit jumper
- 2 Banana plug to banana plug jumpers
- 1 Banana plug shorting bar
- Multimeter
- Watch

Procedure

1. **Verify** the motor's compatibility with the ASD. Refer to the table near the top of page 14 in the User's Manual. For the I_{2hd} value, see page 272. If the motor is compatible continue with the procedure, otherwise stop.
2. **Read** through the start-up instructions in the User's Manual (p. 33-40).
3. **Make** sure that the power supply is turned off.
4. **Make** sure that driven equipment will not be damaged by starting the motor. If the motor is driving another induction machine, make sure that the leads for the driven machine are **NOT** shorted together
5. **Connect** the motor to the ASD using the 3 taper-fit jumpers. Be sure to match the labels (e.g. U2 to U2, etc.). **DO NOT** connect the motor ground to the ASD ground. The motor ground terminal is for measuring voltages only.
6. **Connect** the ASD to the power supply using the 3 SUPERCON® jumpers. Be sure to connect the neutral line of the power supply to the ASD ground terminal using the SUPERCON® to taper-fit jumper.
7. **Use** the banana plug shorting bar to connect GND to DCOM on the ASD digital I/O panel.
8. **Turn** the power supply on.
9. **Follow** the start up instructions that begin on page 33. This model has the Assistant Control Panel so you will have the option to perform the assisted startup on page 38. For parameter values refer to the table below. Parameter 1103 will have to be changed manually. To turn on a digital signal, connect a banana plug jumper between +24V and the desired digital signal.
10. **Once** you have completed the setup be sure to familiarize yourself with the Assistant Control Panel (p. 44-63).

Parameter	Value	Notes
9902	1	ABB Standard Mode
9904	1	Vector: speed control
9905-9909	-	See motor nameplate
9910	0	No ID run
2001		Min. Speed
2002		Max. Speed
2202	5	Acceleration time*
2203	5	Deceleration time
1103	0	Control panel is reference

*Calculated using $t = I \times \text{RPM} / (307.2 \times T)$ where I is the angular inertia (lbm-ft²), RPM is the angular speed (rot/min), and T is the average torque (lbf-in).

Appendix D – Drawing Package

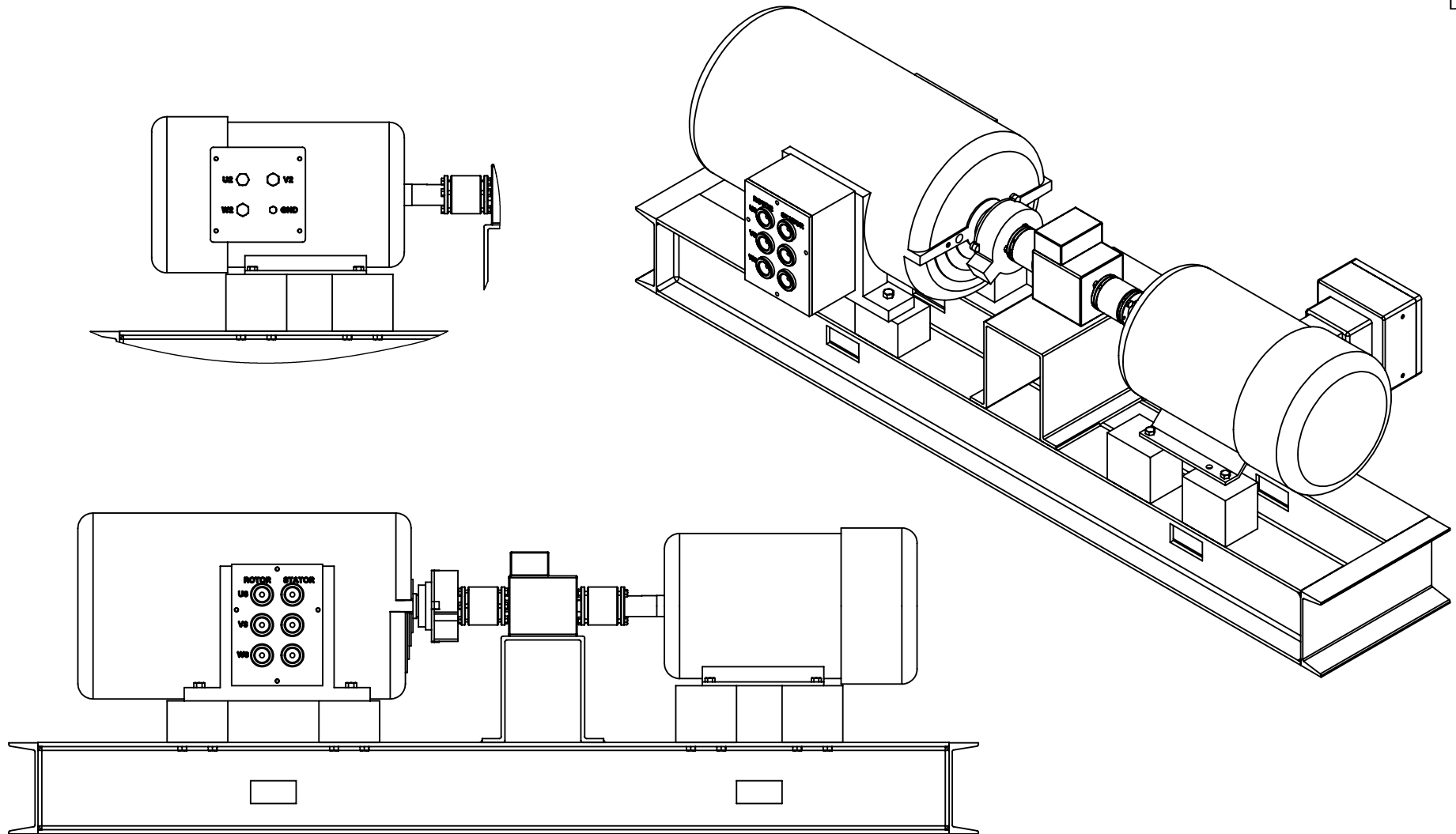
Table of Contents

Frame Assembly D2

Adjustable Speed Drive Cart D14

Power Electronics Cart D22

Wiring Diagrams..... D32

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL:

**DFIG
ENGINEERING**

**UNIVERSITY OF IDAHO
ME DEPARTMENT**

DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0.30°

DESCRIPTION: **Frame Assembly**

CHECKED BY:

DATE:

DRAWN BY: **John Feusi**

DATE: **5/8/2013**

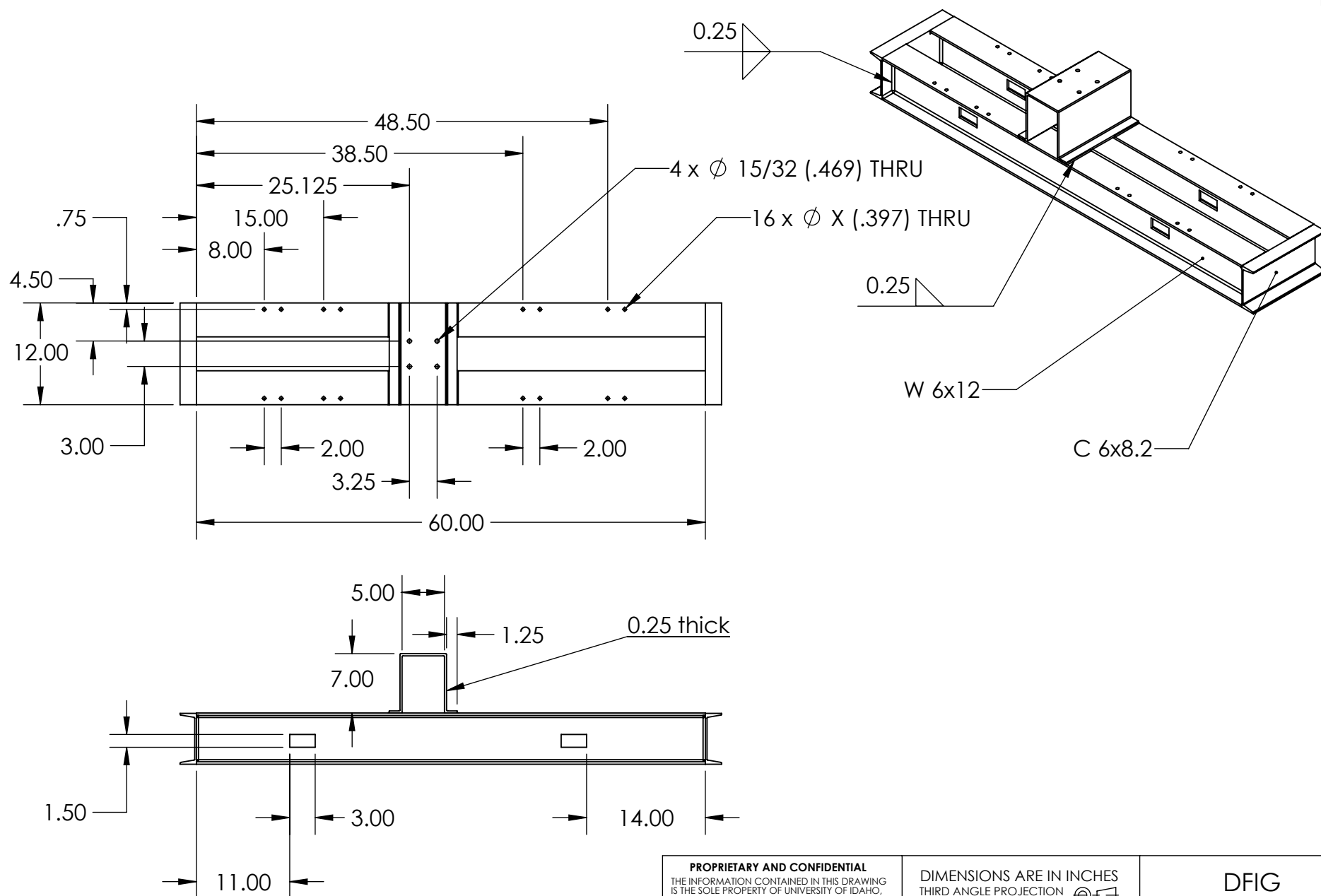
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QTY: **1**

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SHEET: **1 OF 12**

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Mild Steel

**DFIG
ENGINEERING**

**UNIVERSITY OF IDAHO
ME DEPARTMENT**

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0.30'

DESCRIPTION: Frame**CHECKED BY:****DATE:**

DRAWN BY: John Feusi

DATE: 1/28/2013

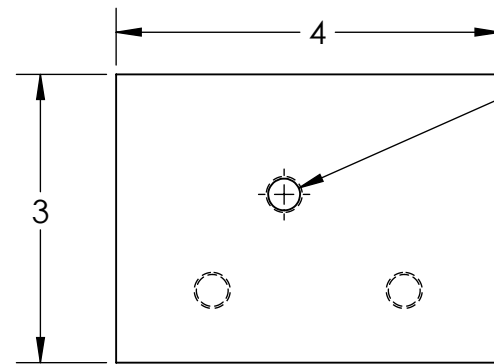
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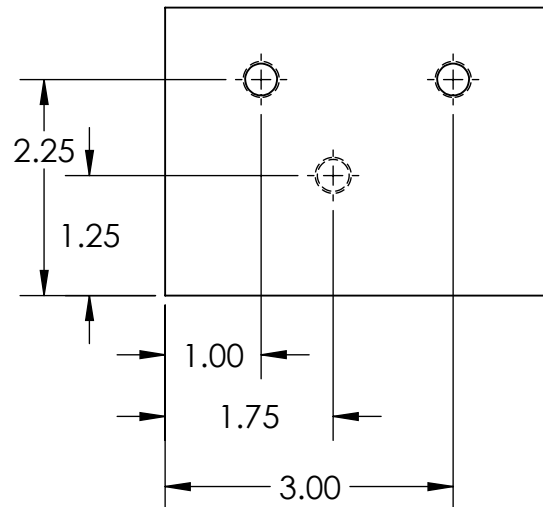
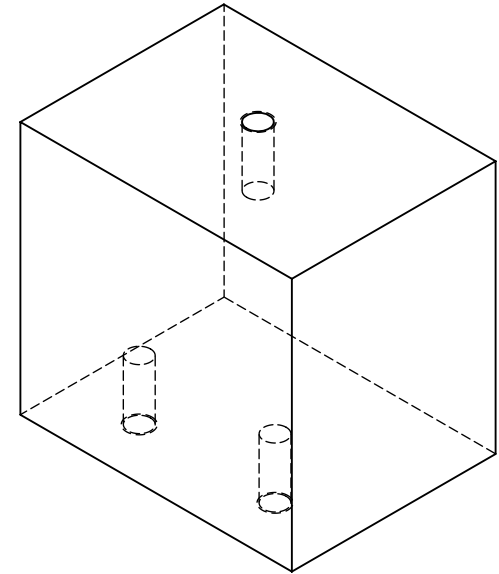
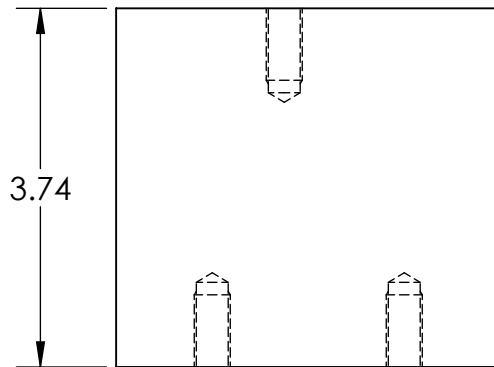
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SHEET: 2 OF 12



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3/8-24 UNF \pm .005



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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Mild Steel

**DFIG
ENGINEERING**

**UNIVERSITY OF IDAHO
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DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: Left 215T Mounting Block

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 1/28/2013

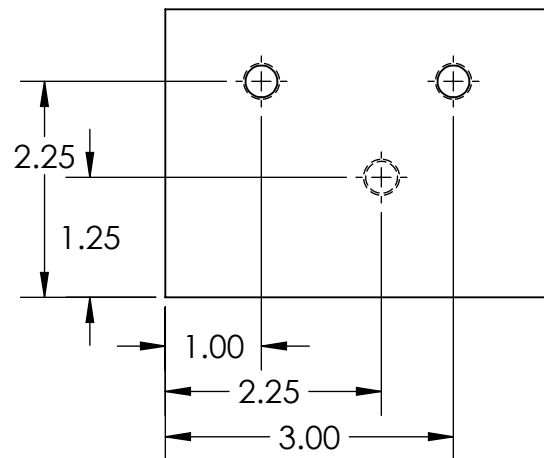
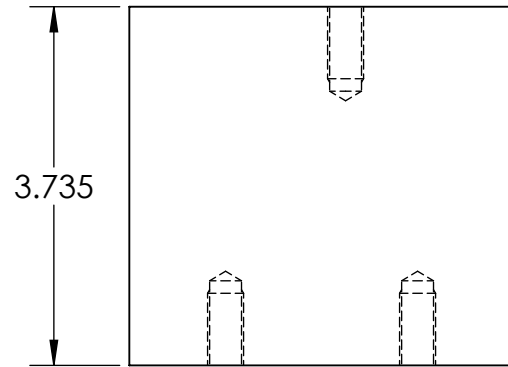
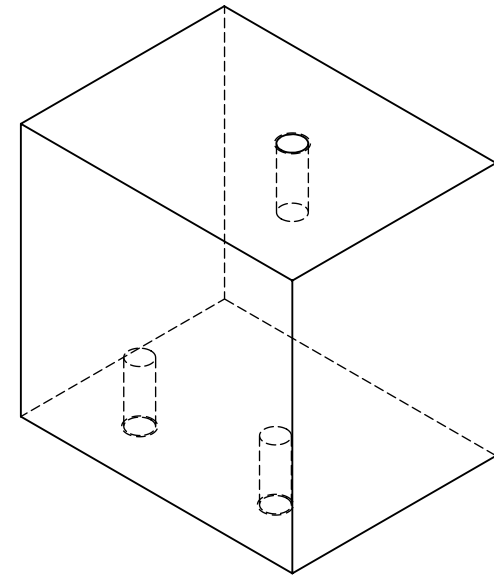
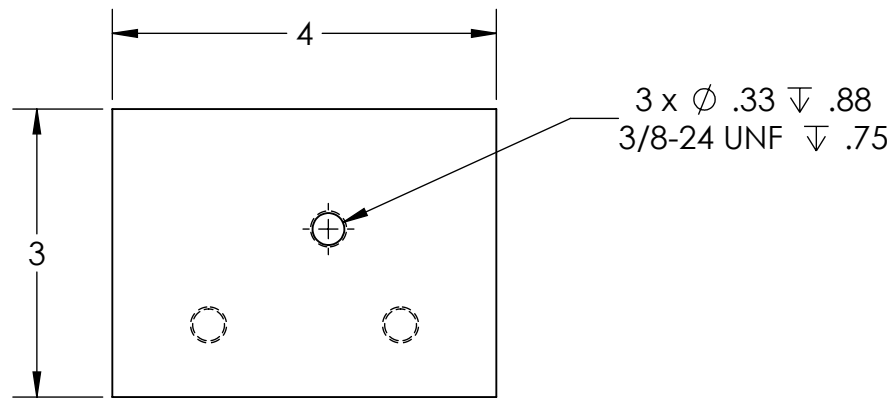
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PART #: A-2

QTY: 2

SCALE: 1:2

SHEET: 3 OF 12

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THIRD ANGLE PROJECTION 

MATERIAL: Mild Steel

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0.30'

DESCRIPTION: Right 215T Mounting Block

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 1/28/2013

FILE NAME: 215T Block (R).SLDPRT

**DFIG
ENGINEERING**

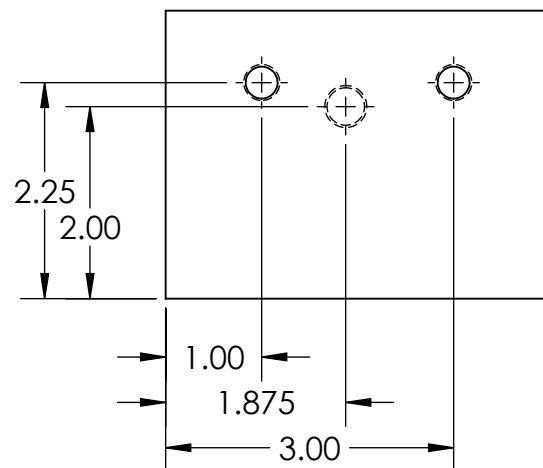
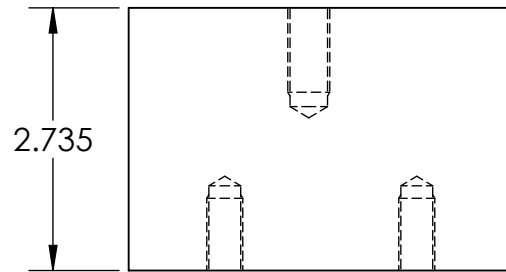
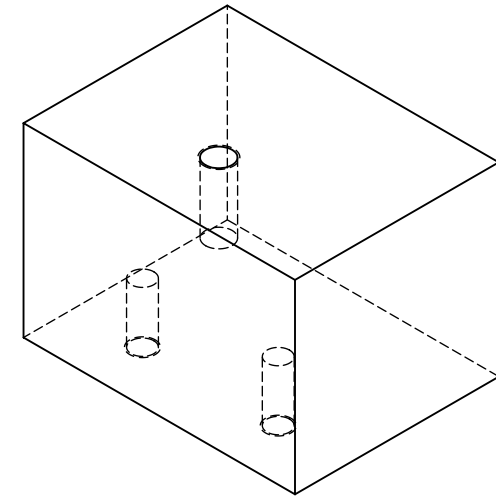
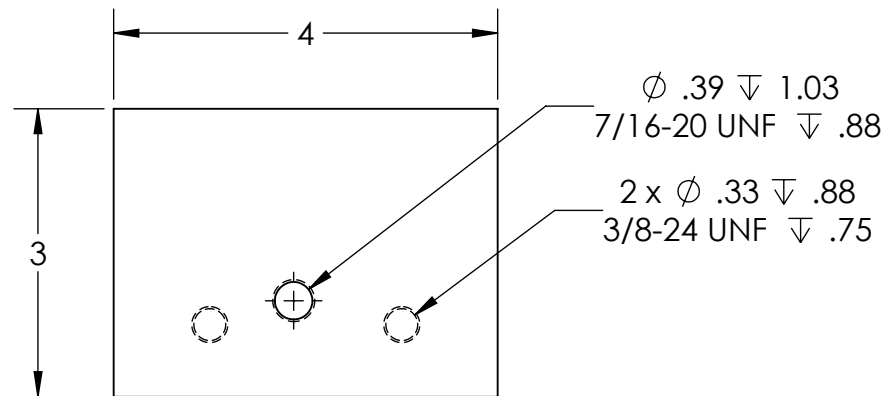
**UNIVERSITY OF IDAHO
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PART #: A-3

QTY: 2

SCALE: 1:2

SHEET: 4 OF 12

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Mild Steel

DFIG
ENGINEERING

UNIVERSITY OF IDAHO
ME DEPARTMENT

DEFAULT TOLERANCES:

LINEAR:
 X. $\pm .25$
 X.X $\pm .1$
 X.XX $\pm .01$
 X.XXX $\pm .002$

ANGULAR:
 X. ± 2
 X.X ± 1
 X.XX $\pm 0.30^\circ$

DESCRIPTION: Left 256U Mounting Block

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 1/28/2013

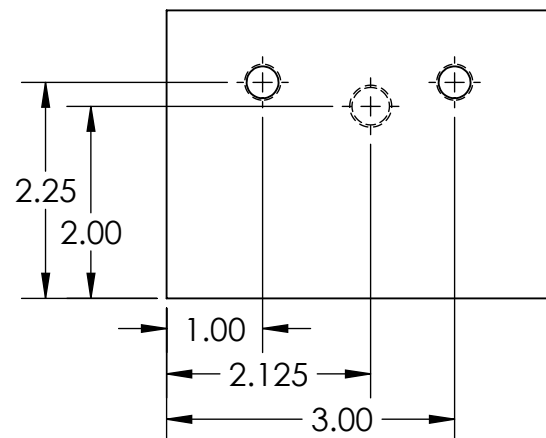
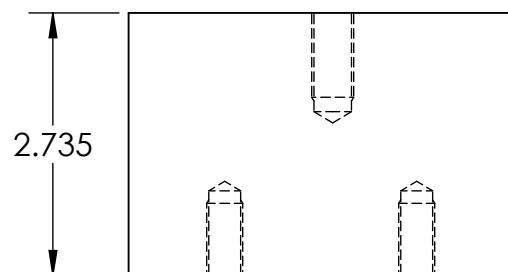
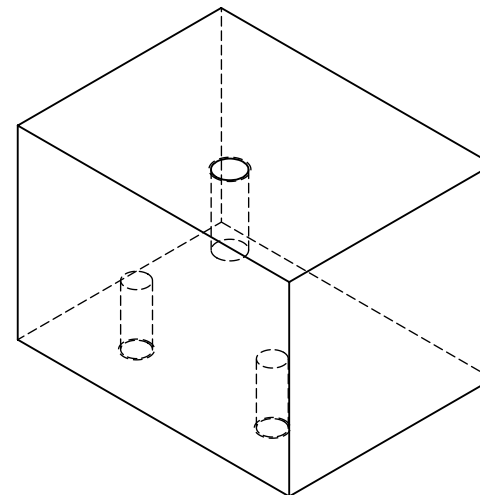
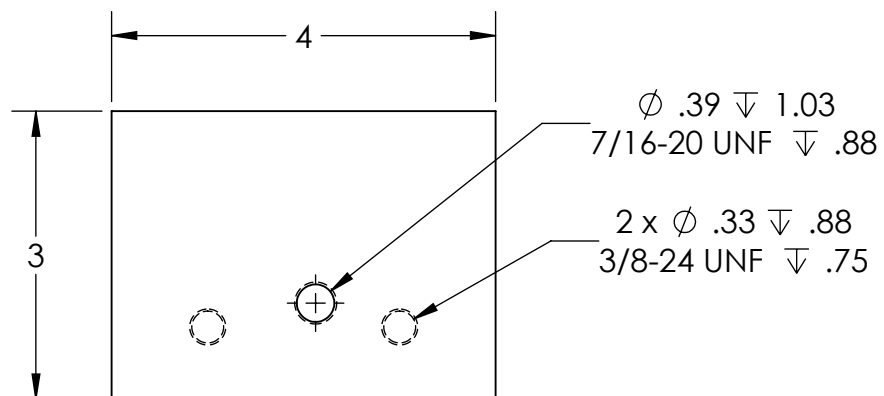
FILE NAME: 256U Block (L).SLDPRT

PART #: A-4

QTY: 2

SCALE: 1:2

SHEET: 5 OF 12

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Mild Steel

DFIG
ENGINEERING

DEFAULT TOLERANCES:

LINEAR:
X. $\pm .25$
X.X $\pm .1$
X.XX $\pm .01$
X.XXX $\pm .002$

ANGULAR:
X. ± 2
X.X ± 1
X.XX $\pm 0.30'$

DESCRIPTION: Right 256U Mounting Block

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 1/28/2013

FILE NAME: 256U Block (R).SLDPRT

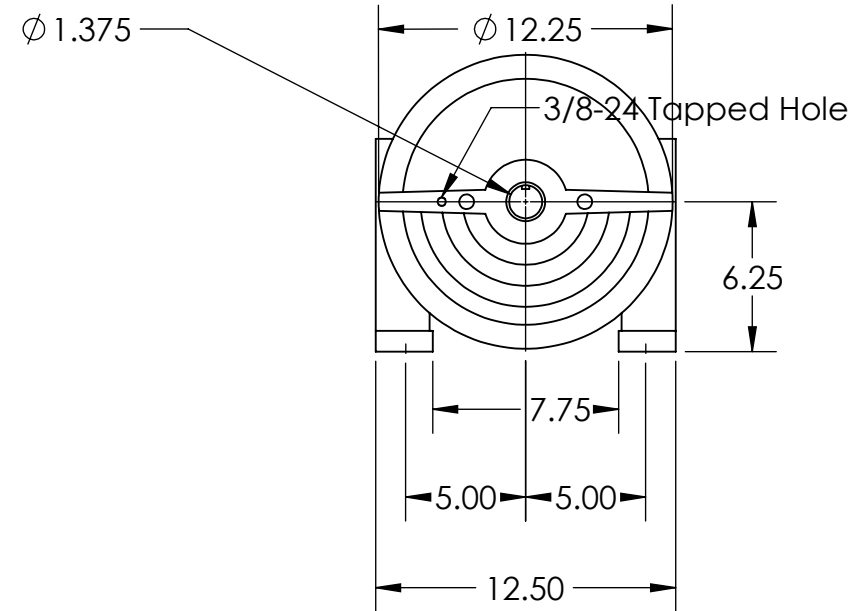
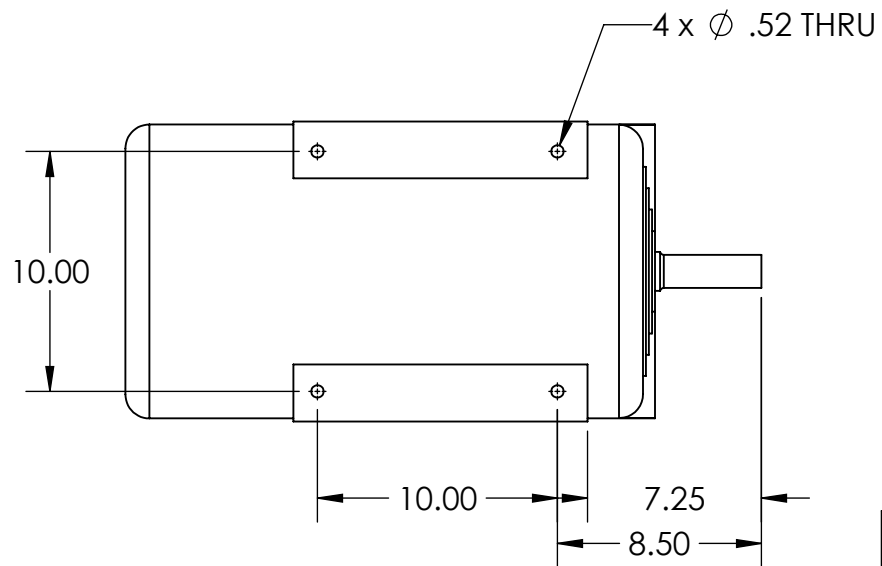
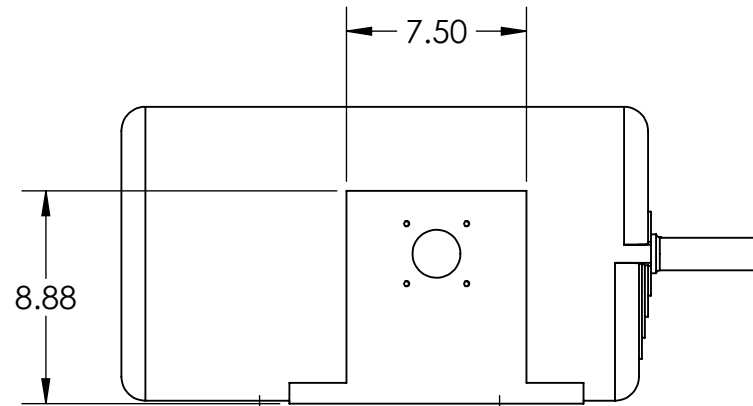
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: A-5

QTY: 2

SCALE: 1:2

SHEET: 6 OF 12

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL:

**DFIG
ENGINEERING**

**UNIVERSITY OF IDAHO
ME DEPARTMENT**

DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0.30'

DESCRIPTION: NEMA 256U Motor (DFIG)

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 5/7/2013

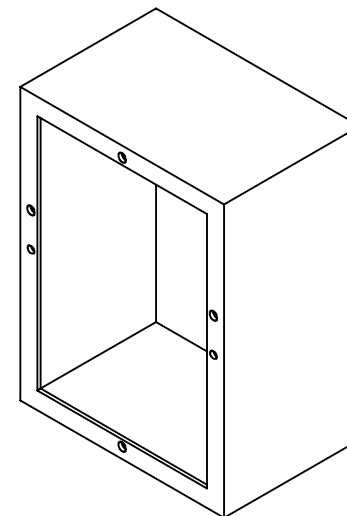
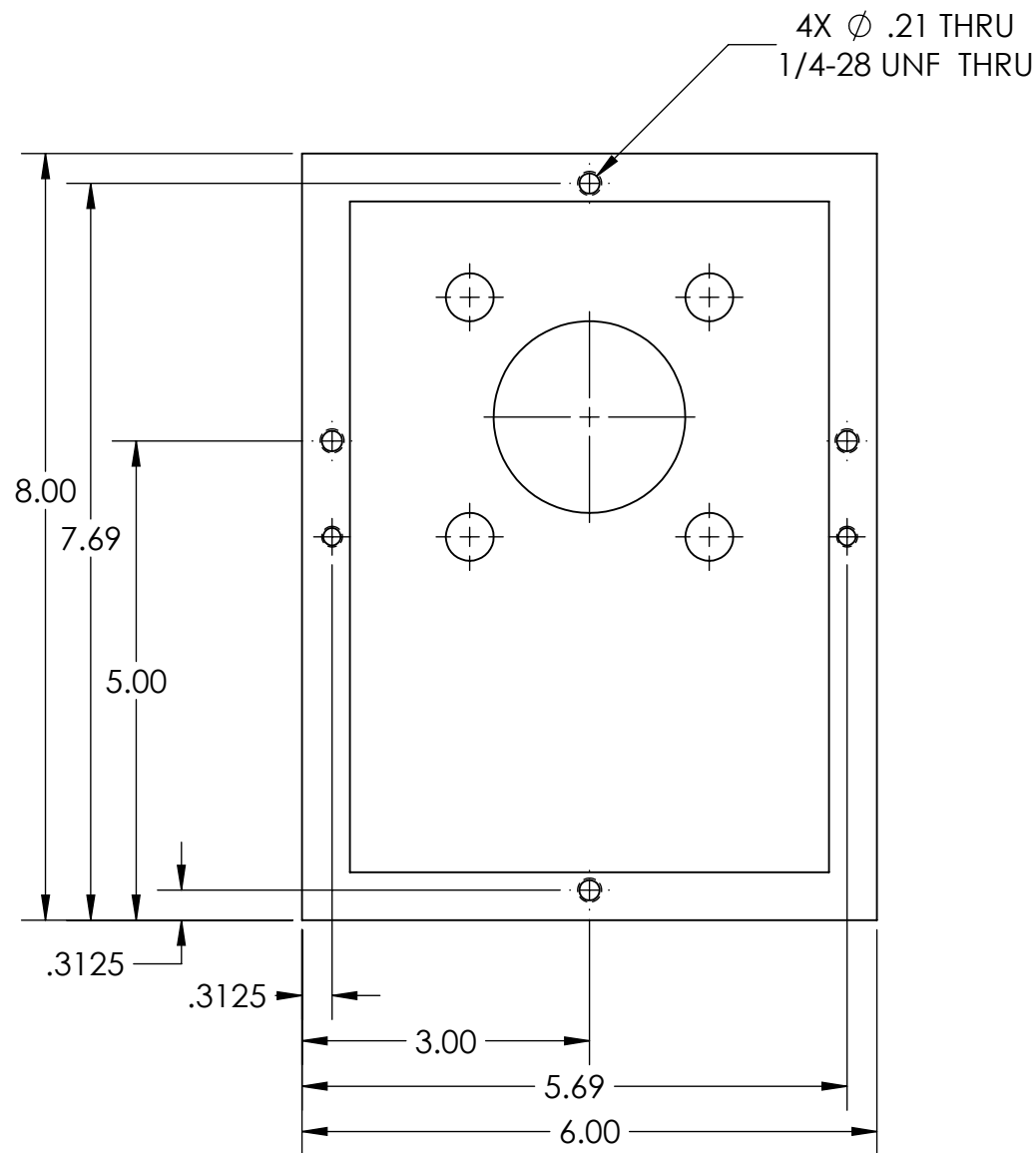
FILE NAME: NEMA 256U.SLDPRT

PART #: A-6

QTY: 1

SCALE: 1:8

SHEET: 7 OF 12

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Sheet Metal

**DFIG
ENGINEERING**

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: DFIG Connection Box

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 2/7/2013

FILE NAME: DFIG Box.SLDPR

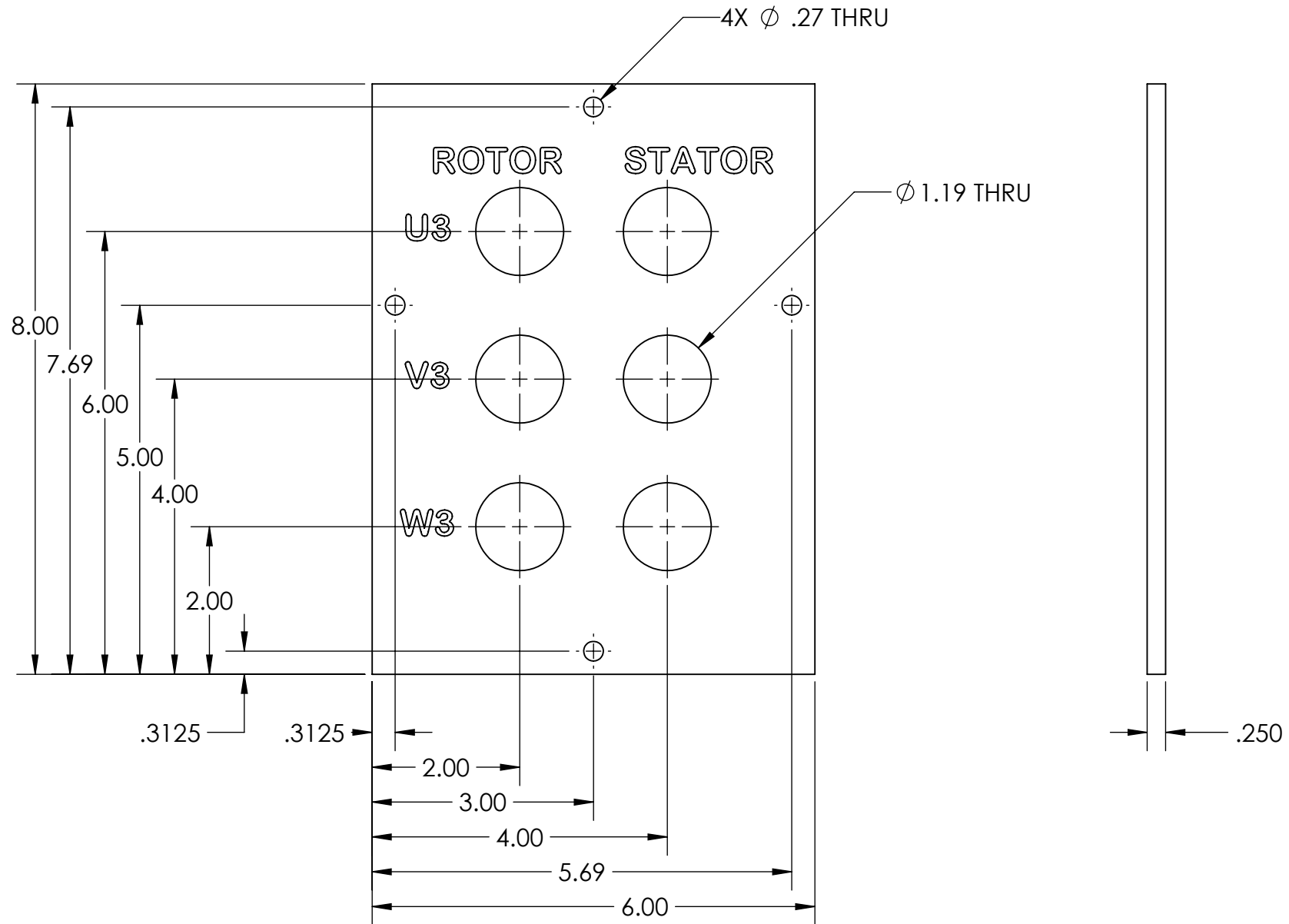
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: A-7

QTY: 1

SCALE: 1:2

SHEET: 8 OF 12

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Plexiglas

**DFIG
ENGINEERING**

DEFAULT TOLERANCES:

LINEAR:
X. $\pm .25$
X.X $\pm .1$
X.XX $\pm .01$
X.XXX $\pm .002$

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0.30

DESCRIPTION: DFIG Connection Plate

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 5/7/2013

FILE NAME: DFIG Cover Plate2.SLDPR

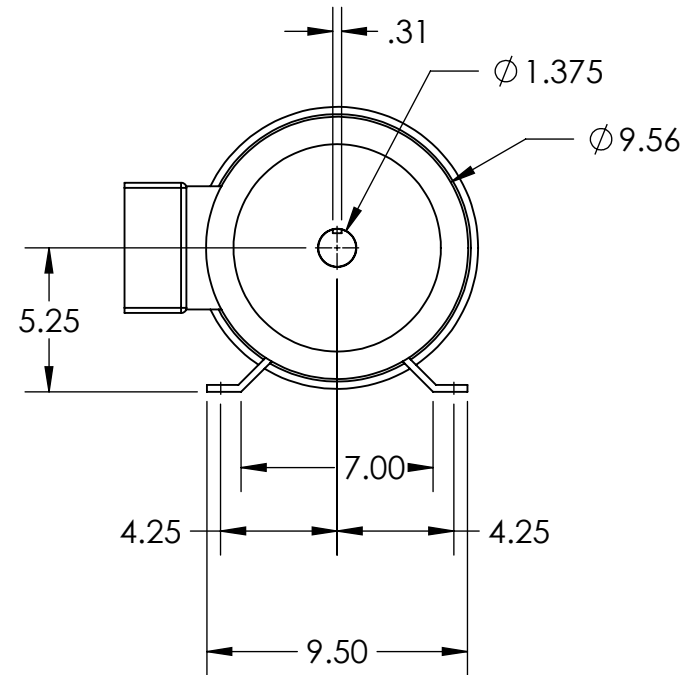
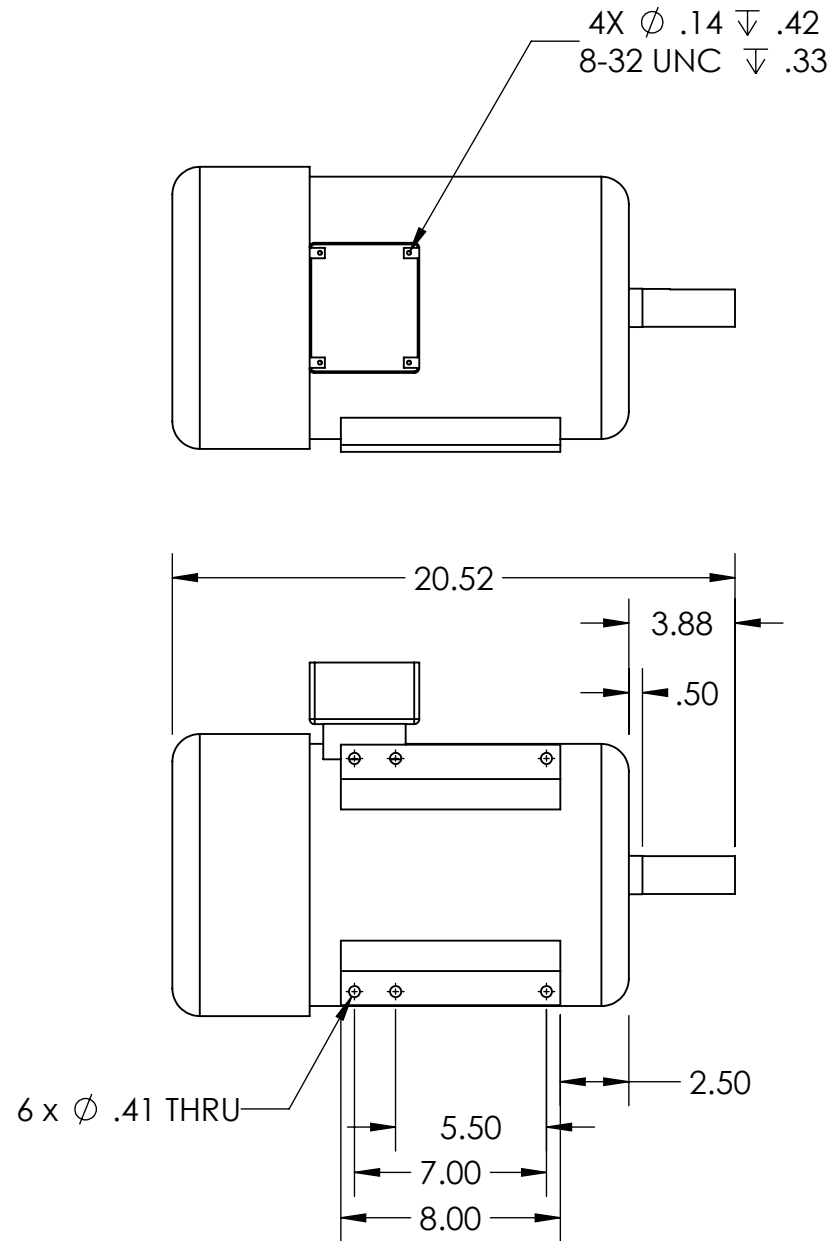
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: A-8

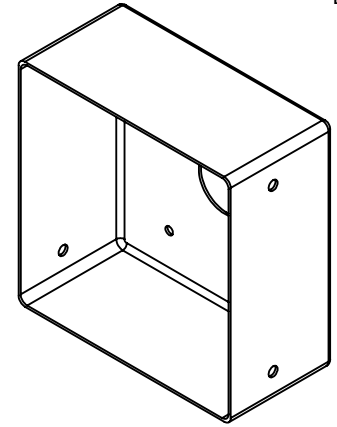
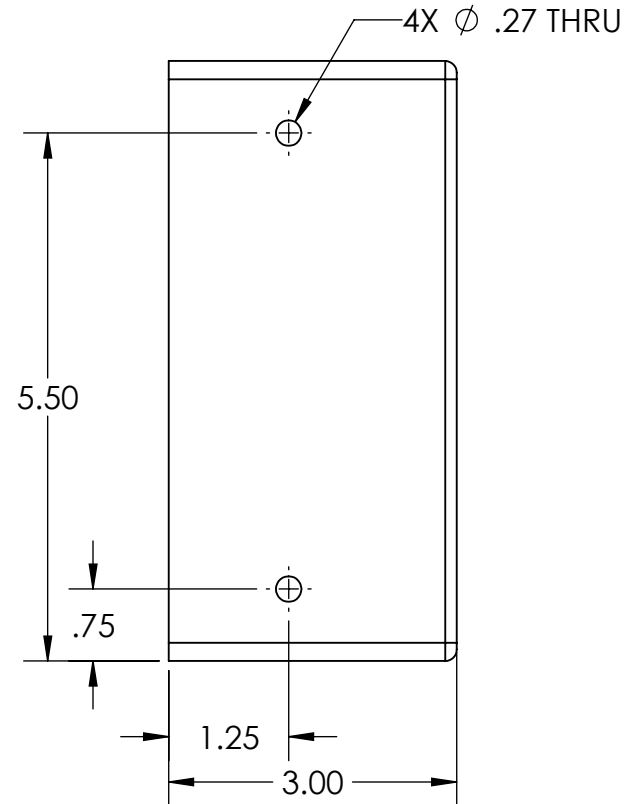
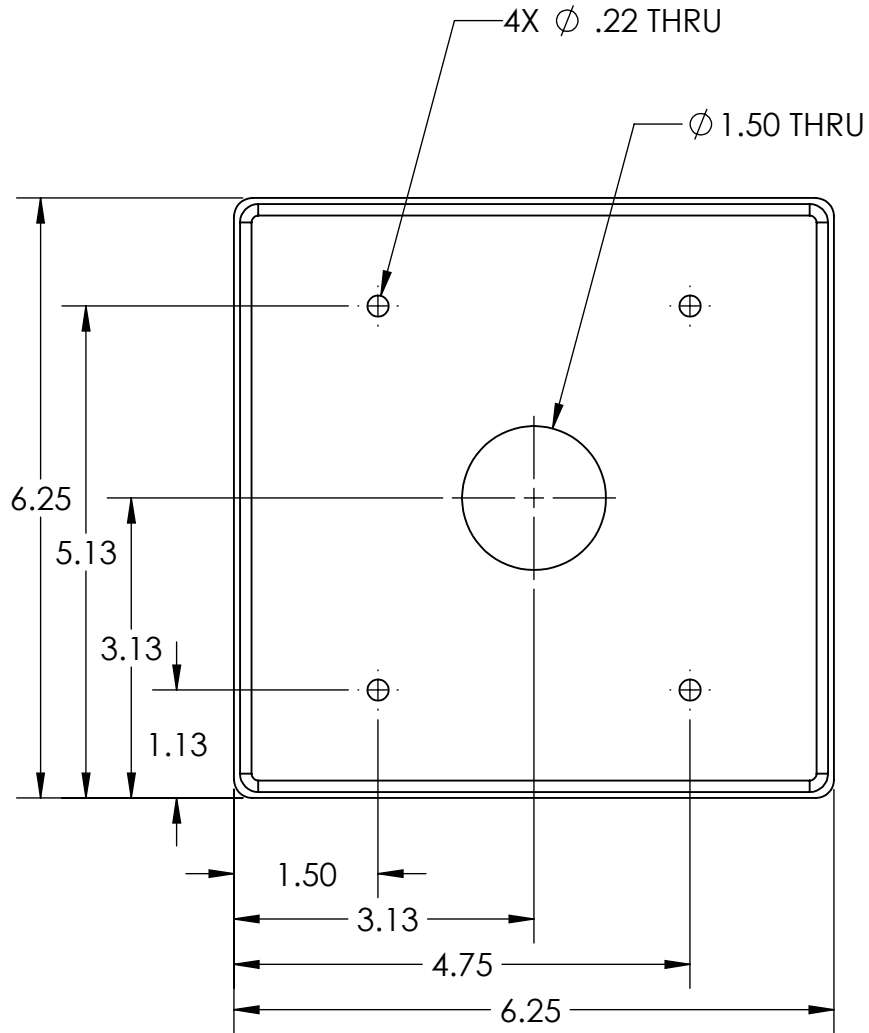
QTY: 1

SCALE: 1:2

SHEET: 9 OF 12



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DEFAULT TOLERANCES: LINEAR: X. \pm .25 X.X \pm .1 X.XX \pm .01 X.XXX \pm .002		DESCRIPTION: NEMA 215T Motor (SCIM)		UNIVERSITY OF IDAHO ME DEPARTMENT	
ANGULAR: X. \pm 2 X.X \pm 1 X.XX \pm 0 30'		CHECKED BY:		DATE:	
DRAWN BY: John Feusi		DATE: 1/16/2013		PART #: A-9	
FILE NAME: NEMA 215T.SLDPR		SCALE: 1:7		QTY: 1	
				SHEET: 10 OF 12	

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Aluminum

DFIG
ENGINEERING

DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0.30°

DESCRIPTION: SCIM Connection Box

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 2/11/2013

FILE NAME: 6.25x6.25 Deep Drawn Enclosure.SLDPR

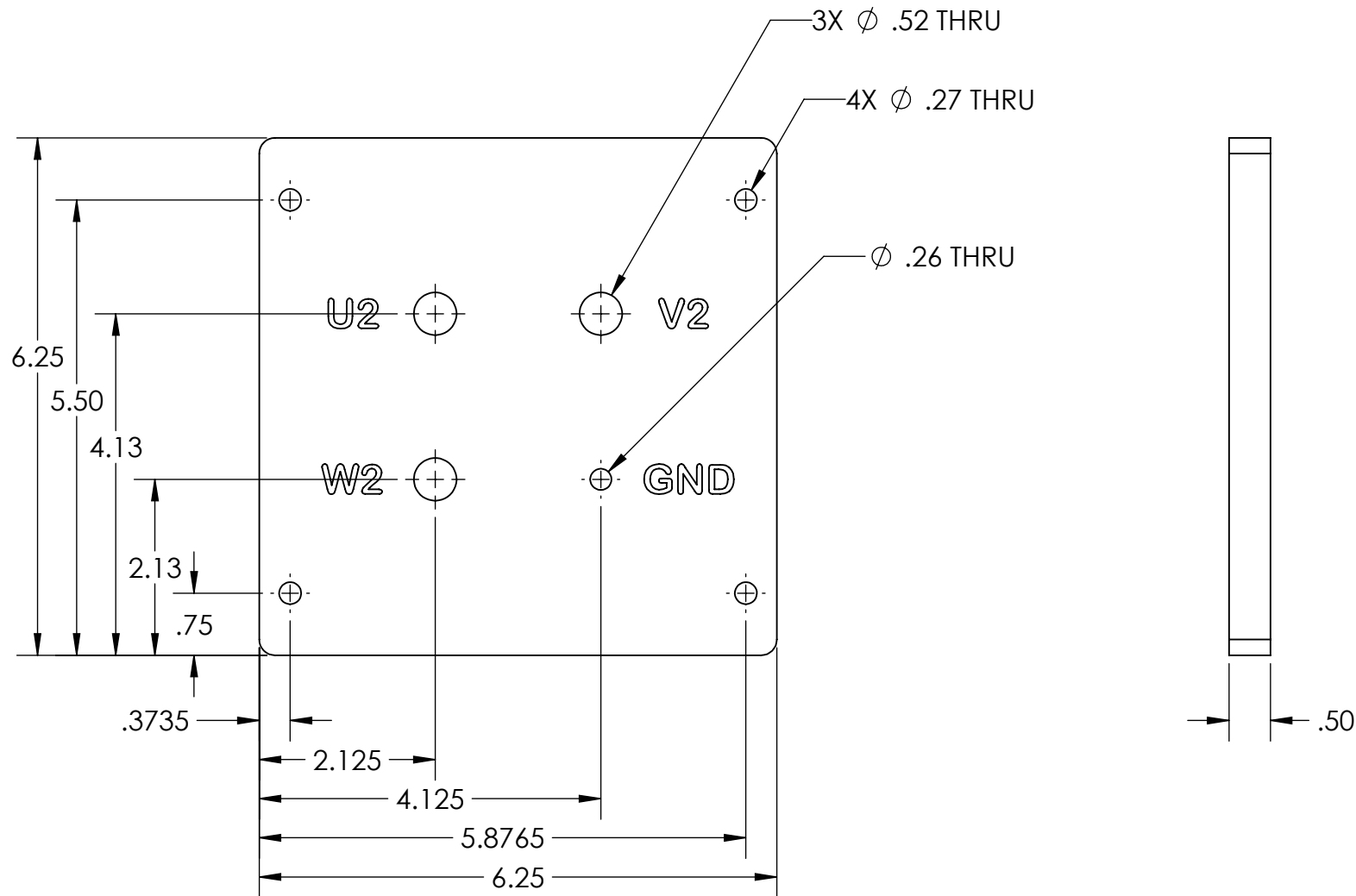
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: A-10

QTY: 1

SCALE: 1:2

SHEET: 11 OF 12

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Plexiglas

DFIG
ENGINEERING

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: SCIM Connection Plate

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 2/13/2013

FILE NAME: SCIM Cover Plate.SLDPR

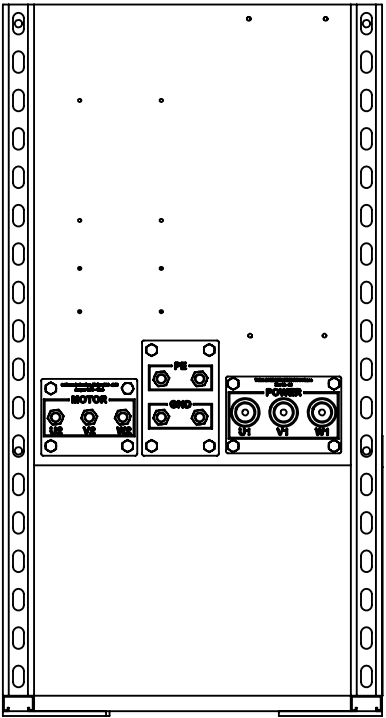
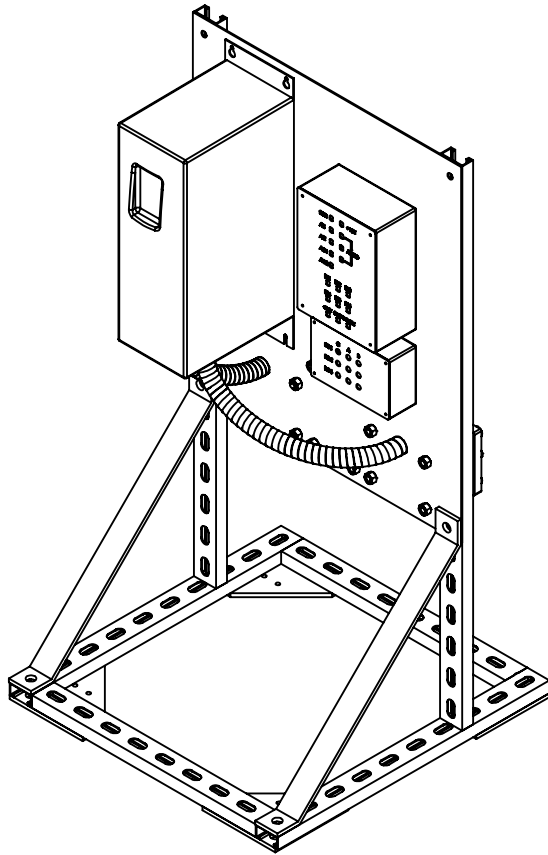
**UNIVERSITY OF IDAHO
ME DEPARTMENT**


PART #: A-11

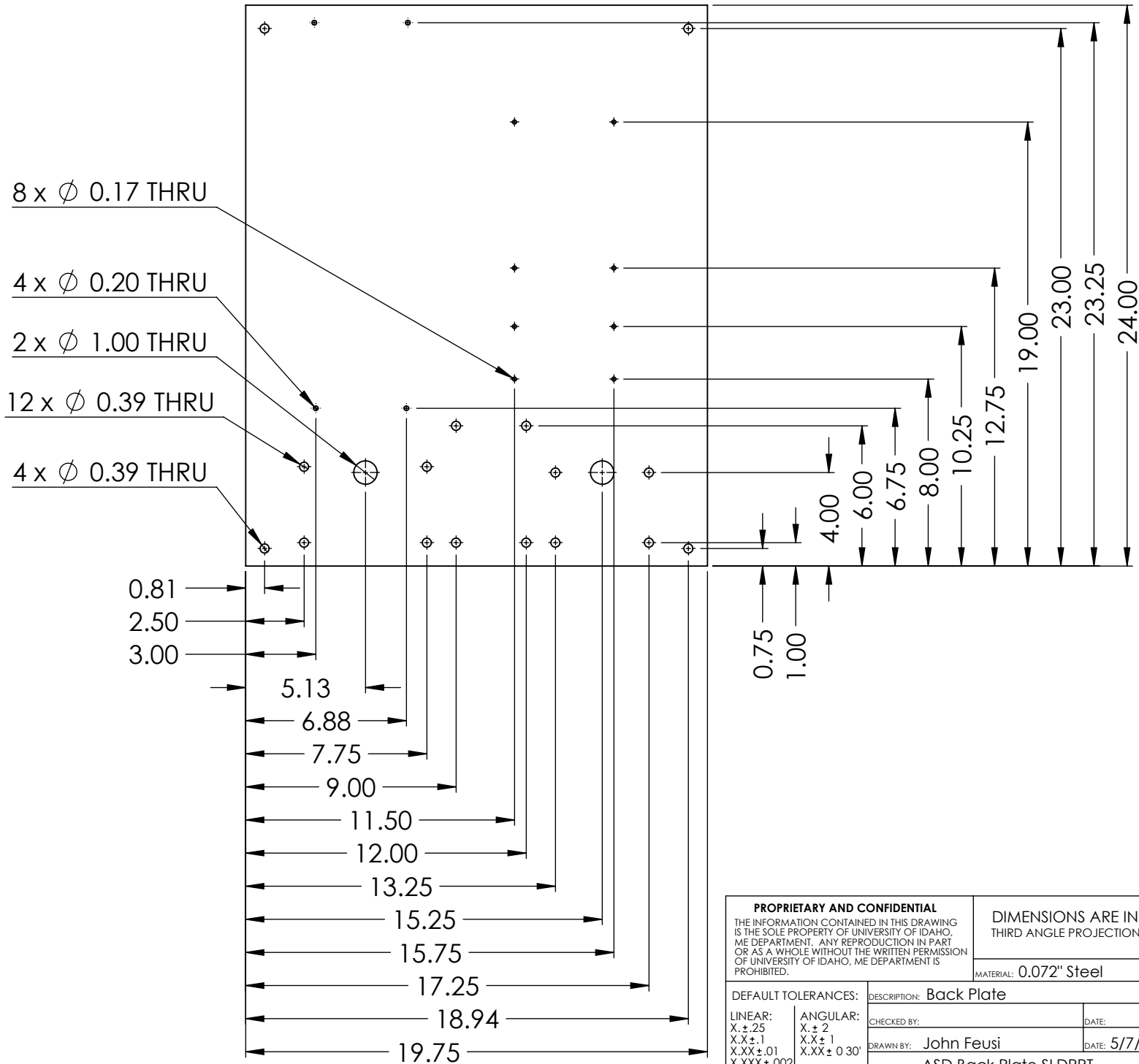
QTY: 1

SCALE: 1:2

SHEET: 12 OF 12



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DEFAULT TOLERANCES: LINEAR: X. ± .25 X.X ± .1 X.XX ± .01 X.XXX ± .002		DESCRIPTION: ASD Cart		UNIVERSITY OF IDAHO ME DEPARTMENT	
ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'		CHECKED BY:	DATE:	PART #: B	QTY: 1
DRAWN BY: John Feusi		DATE: 5/8/2013		SCALE: 1:10	
FILE NAME: ASD Cart.SLDPR				SHEET: 1 OF 8	

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: 0.072" Steel

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: Back Plate

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 5/7/2013

FILE NAME: ASD Back Plate.SLDPR

**DFIG
ENGINEERING**

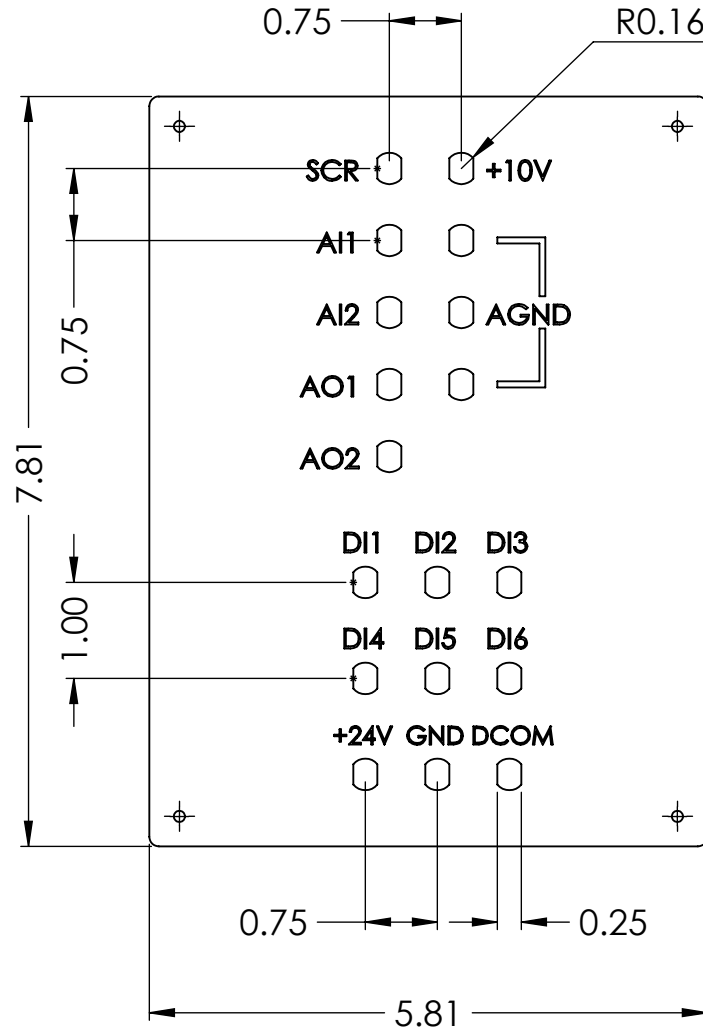
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: B-1

QTY: 1

SCALE: 1:6

SHEET: 2 OF 8

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Aluminum

**DFIG
ENGINEERING**

DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0.30'

DESCRIPTION: 8x6x3 Cover Plate for ASD I/O

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 12/9/2012

FILE NAME: Project Enclosure Plate 8x6x3.SLDPR

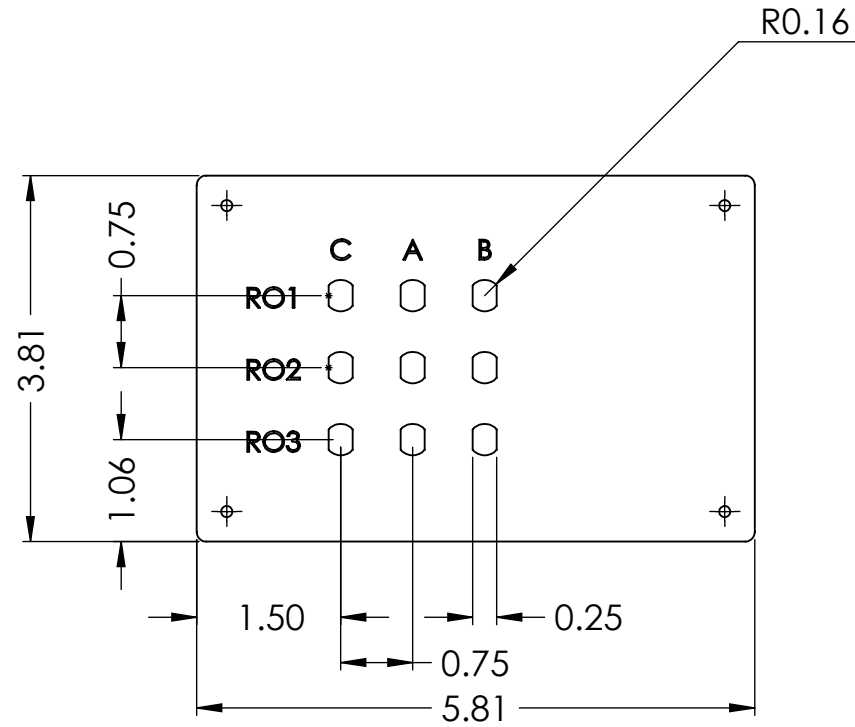
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: B-2

QTY: 1

SCALE: 1:2

SHEET: 3 OF 8

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Aluminum

**DFIG
ENGINEERING**

DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0.30°

DESCRIPTION: 6x4x2 Cover Plate for ASD Relays

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 12/9/2012

FILE NAME: Project Enclosure Plate 6x4x2.SLDPRT

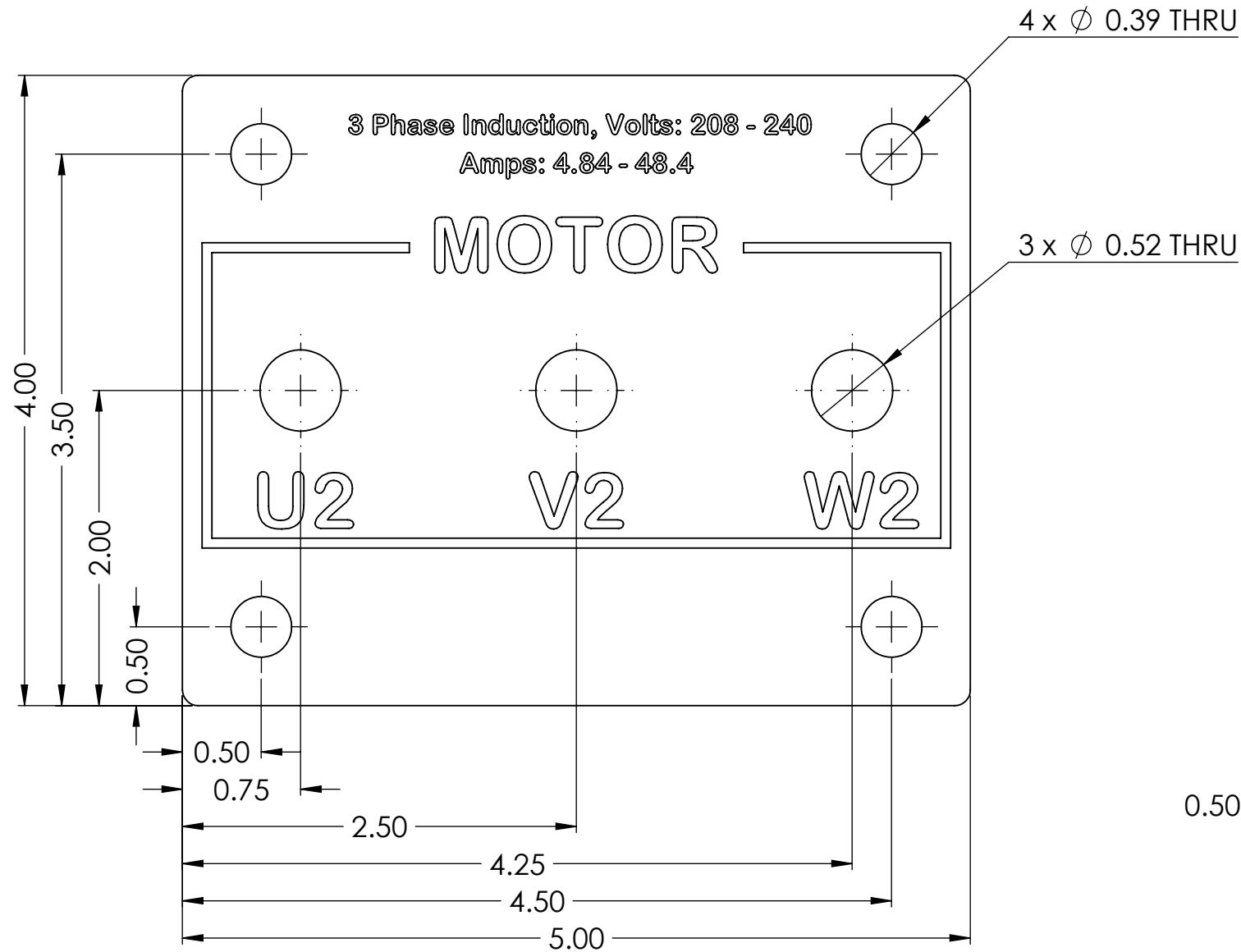
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: B-3

QTY: 1

SCALE: 1:2

SHEET: 4 OF 8

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Plexiglas

**DFIG
ENGINEERING**

DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0.30°

DESCRIPTION: ASD Motor Connection Plate

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 3/28/2013

FILE NAME: Motor Output Plate.SLDPR

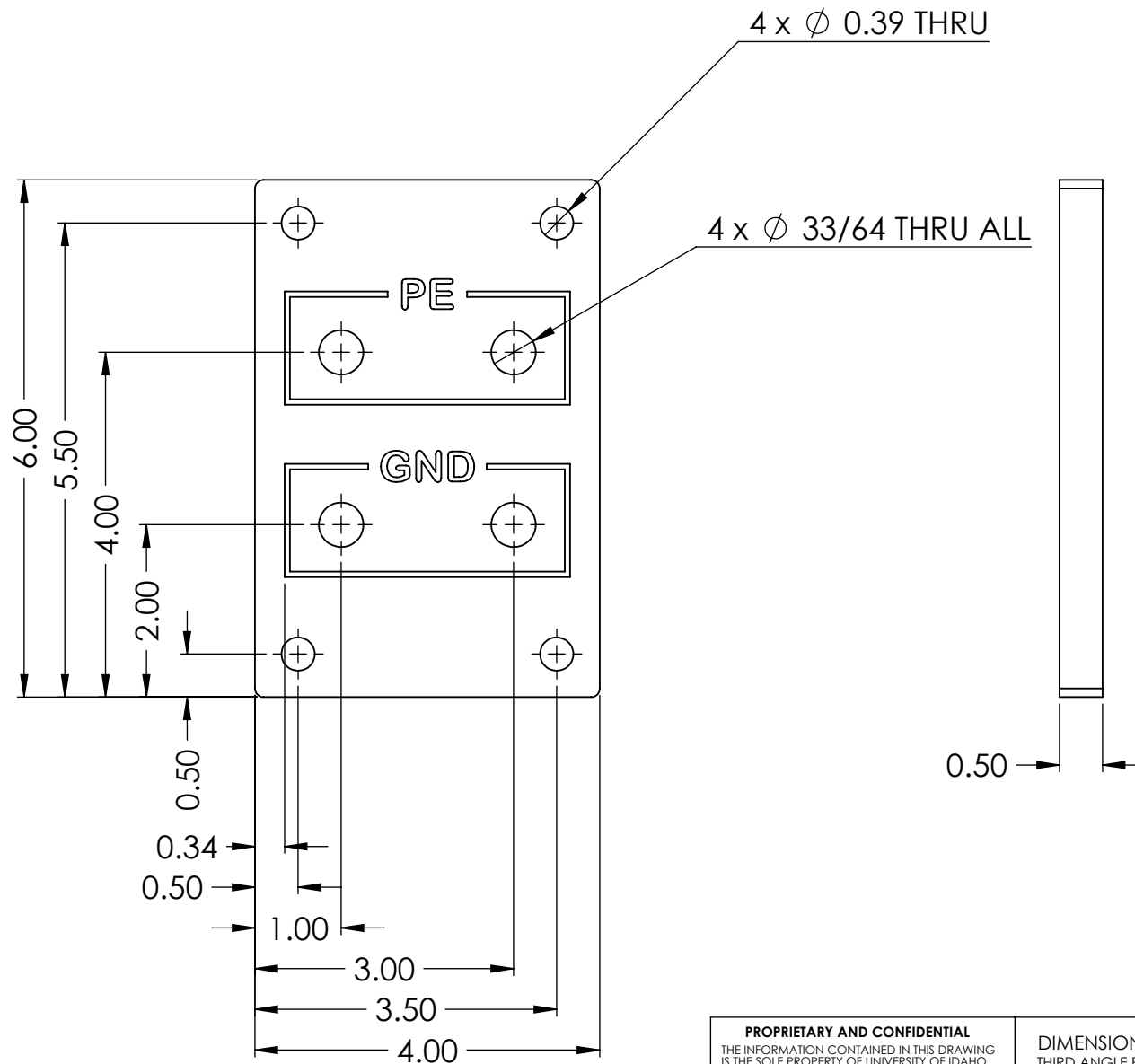
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: B-4

QTY: 1

SCALE: 1:1

SHEET: 5 OF 8

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Plexiglas

**DFIG
ENGINEERING**

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: ASD Ground Connection Plate

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 12/3/2012

FILE NAME: Ground Plate.SLDprt

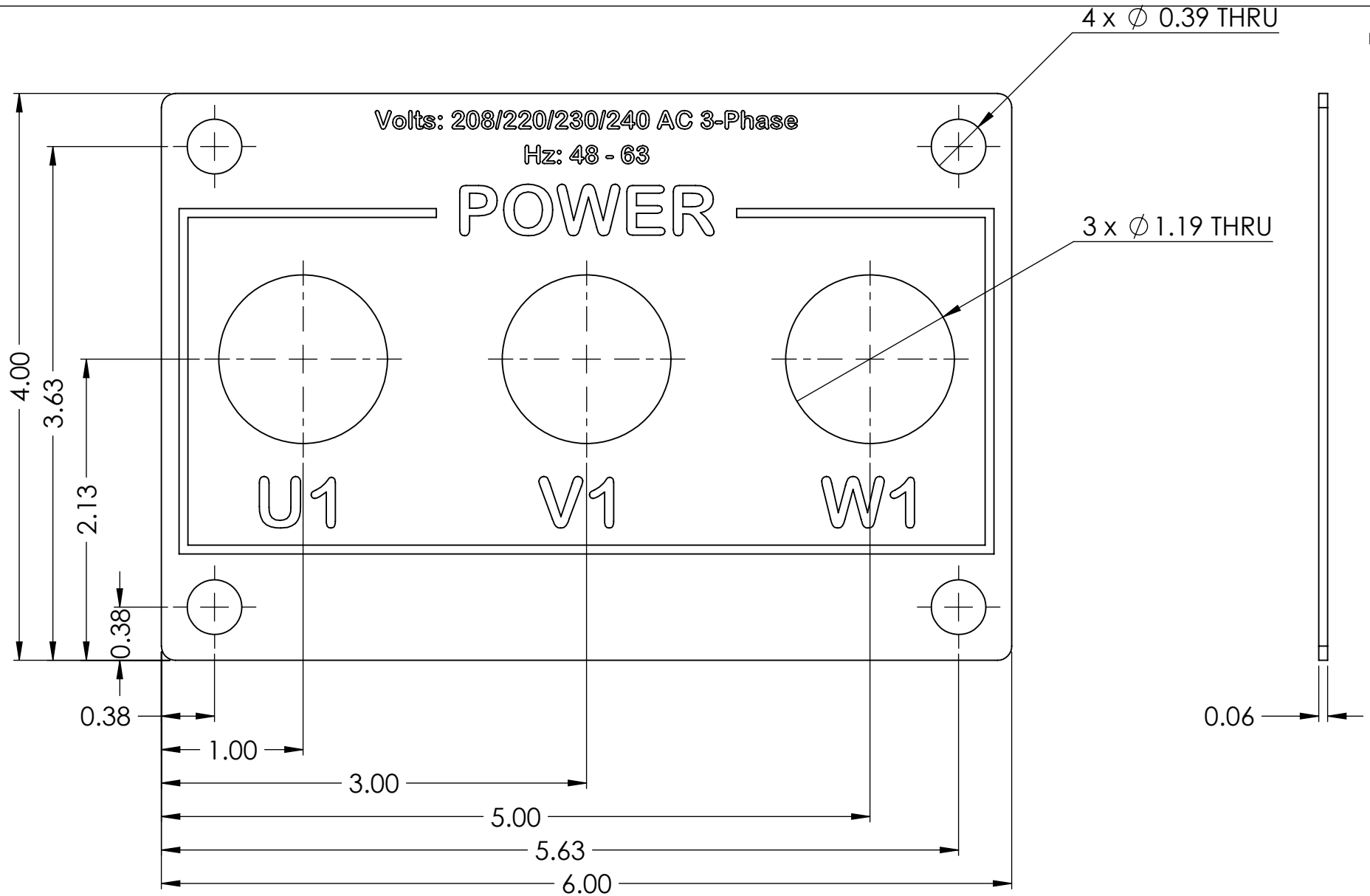
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PART #: B-5

QTY: 1

SCALE: 1:2

SHEET: 6 OF 8

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Aluminum

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: ASD Power Connection Plate

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 3/28/2013

FILE NAME: Power Input Plate.SLDPRT

DFIG
ENGINEERING

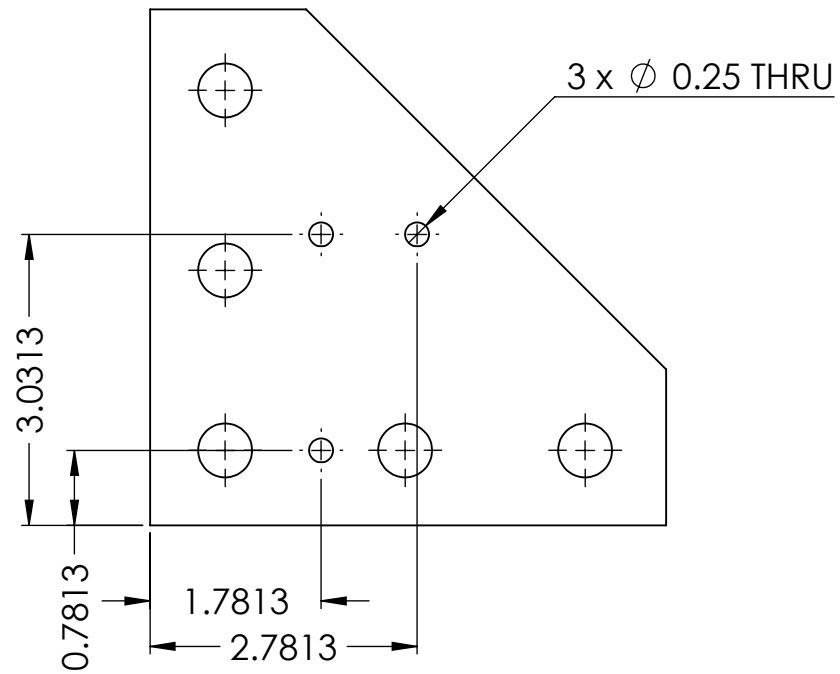
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: B-6

QTY: 1

SCALE: 1:1

SHEET: 7 OF 8

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Zinc Plated Steel

**DFIG
ENGINEERING**

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: Connecting Plate Style 5 for Castors

CHECKED BY:

DATE:

DRAWN BY:

DATE: 11/8/2012

FILE NAME:

Connecting Plate Style 5.SLDPRT

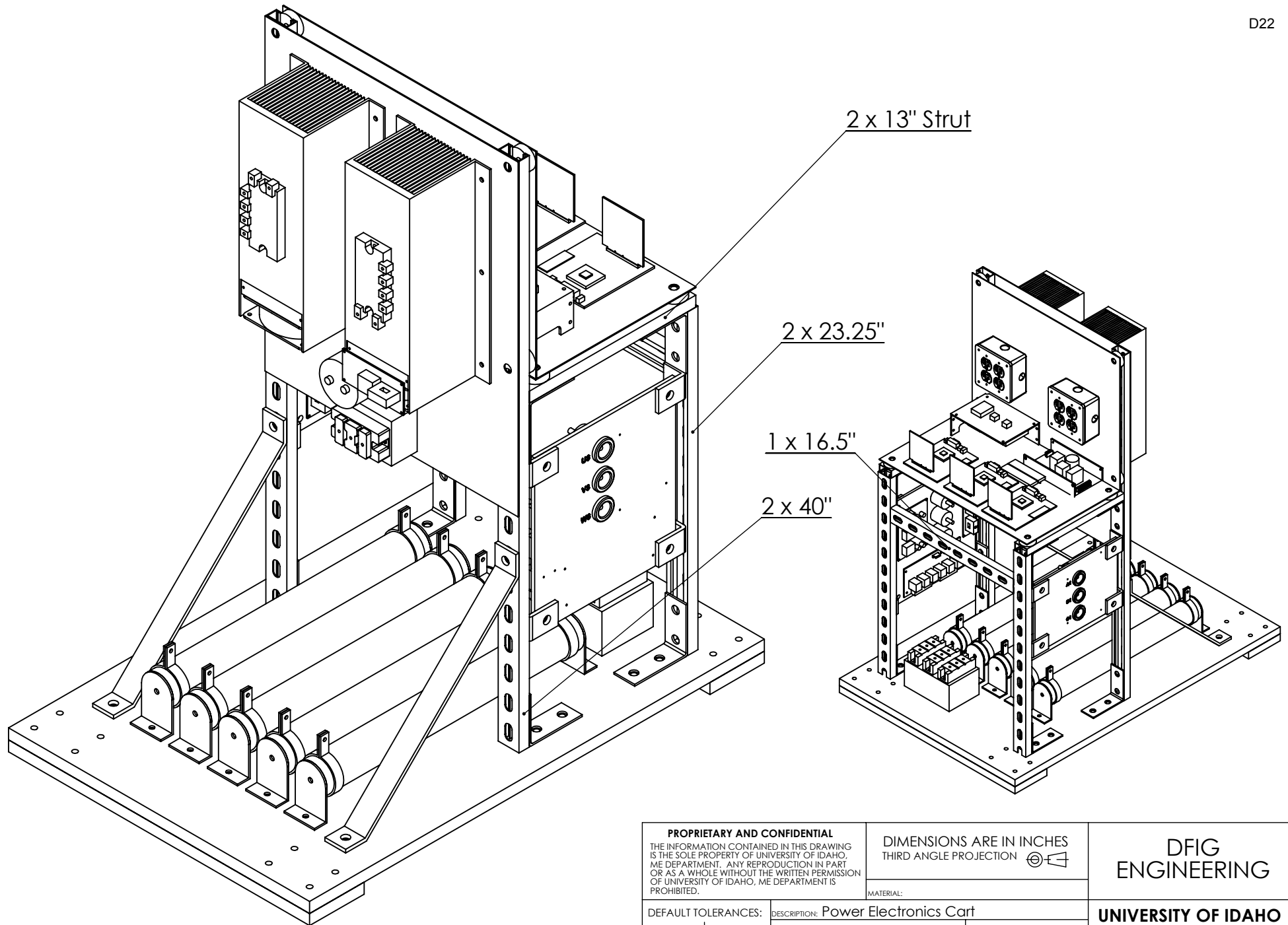
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: B-7

QTY: 4

SCALE: 1:2

SHEET: 8 OF 8

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL:

**DFIG
ENGINEERING**

DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ± .25	X. ± 2
X.X ± .1	X.X ± 1
X.XX ± .01	X.XX ± 0.30
X.XXX ± .002	

DESCRIPTION: Power Electronics Cart

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 5/8/2013

FILE NAME: PE Cart.SLDPR

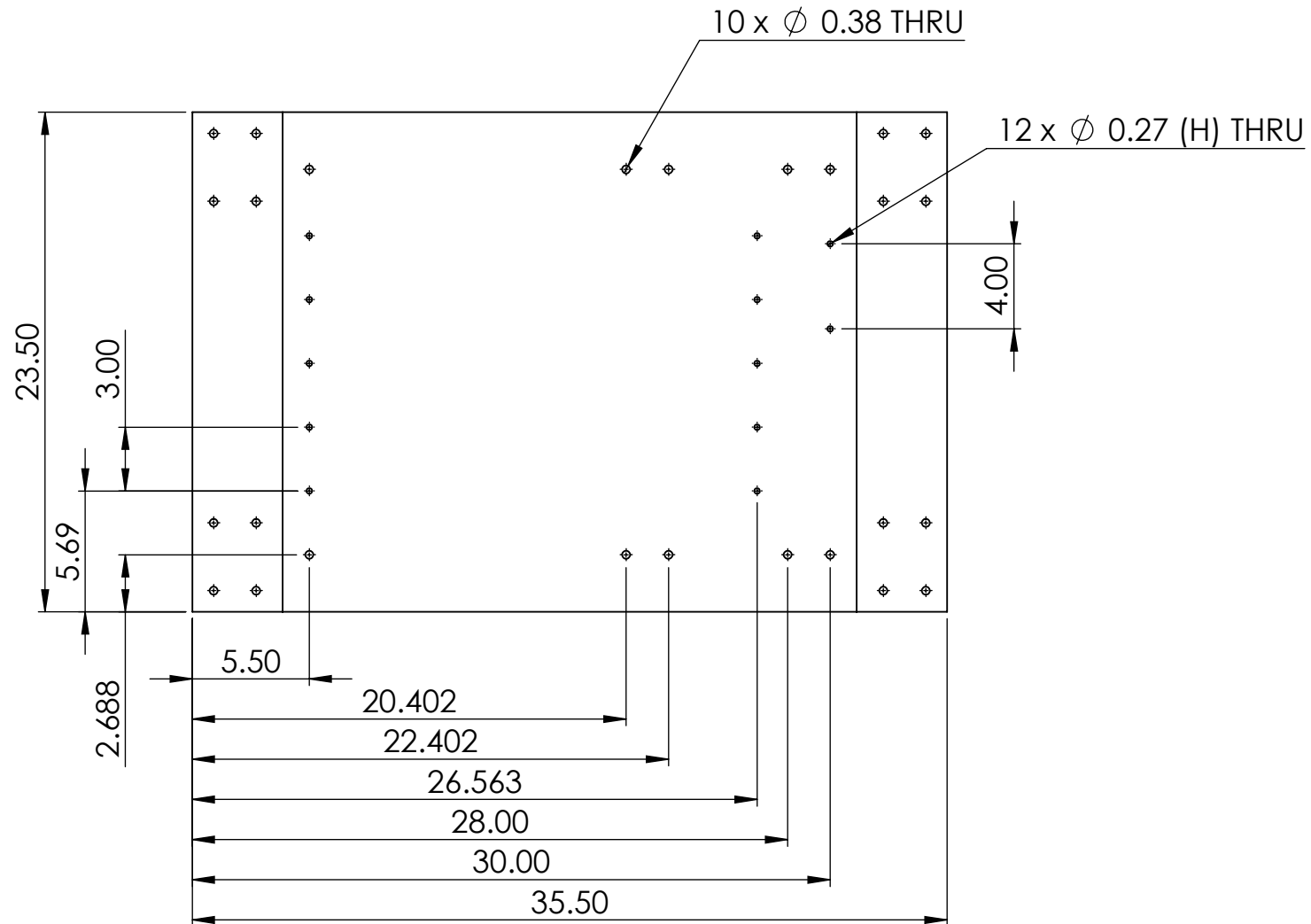
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: C

QTY: 1

SCALE: 1:7

SHEET: 1 OF 10

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Hardwood

**DFIG
ENGINEERING**

**UNIVERSITY OF IDAHO
ME DEPARTMENT**

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: Dolly

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 5/7/2013

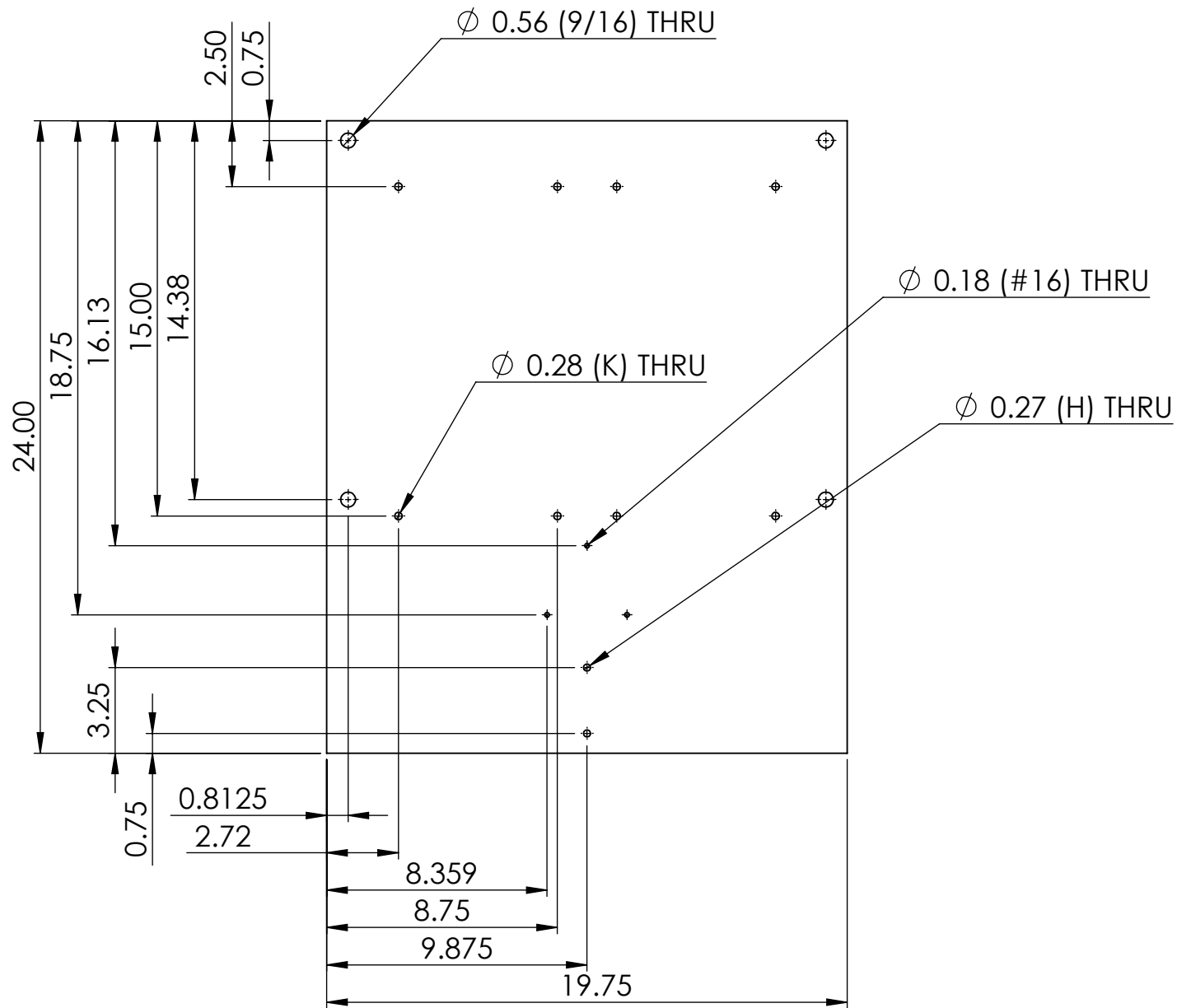
FILE NAME: Dolly.SLDPR

PART #: C-1

QTY: 1

SCALE: 1:8

SHEET: 2 OF 10

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: 0.072" Steel

**DFIG
ENGINEERING**

**UNIVERSITY OF IDAHO
ME DEPARTMENT**

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: Back Plate

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 5/7/2013

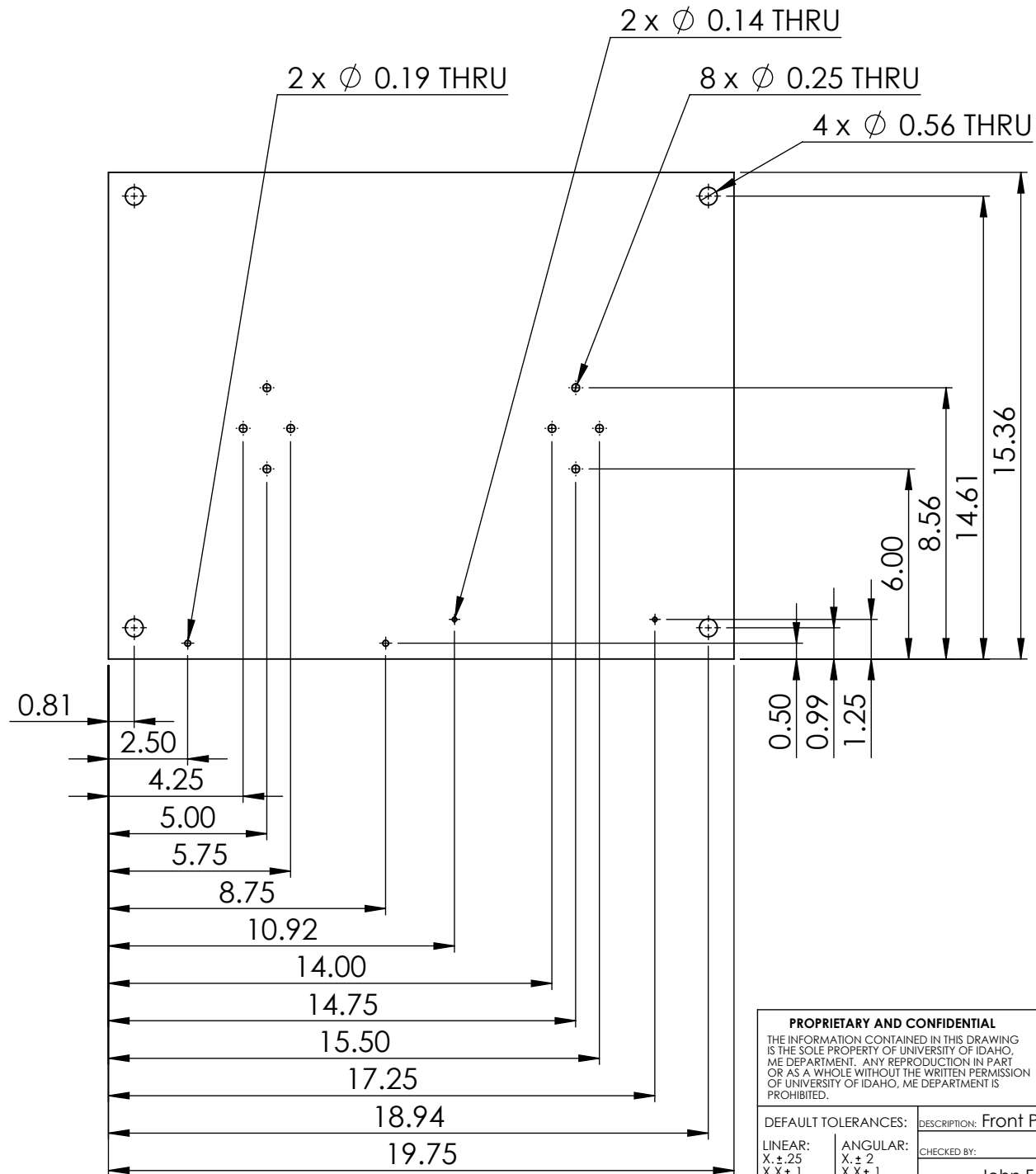
FILE NAME: Back Plate.SLDPR

PART #: C-2

QTY: 1

SCALE: 1:6

SHEET: 3 OF 10

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: 0.075" Steel

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0.30'

DESCRIPTION: Front Plate

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 5/8/2013

FILE NAME: Front Plate.SLDPR

**DFIG
ENGINEERING**

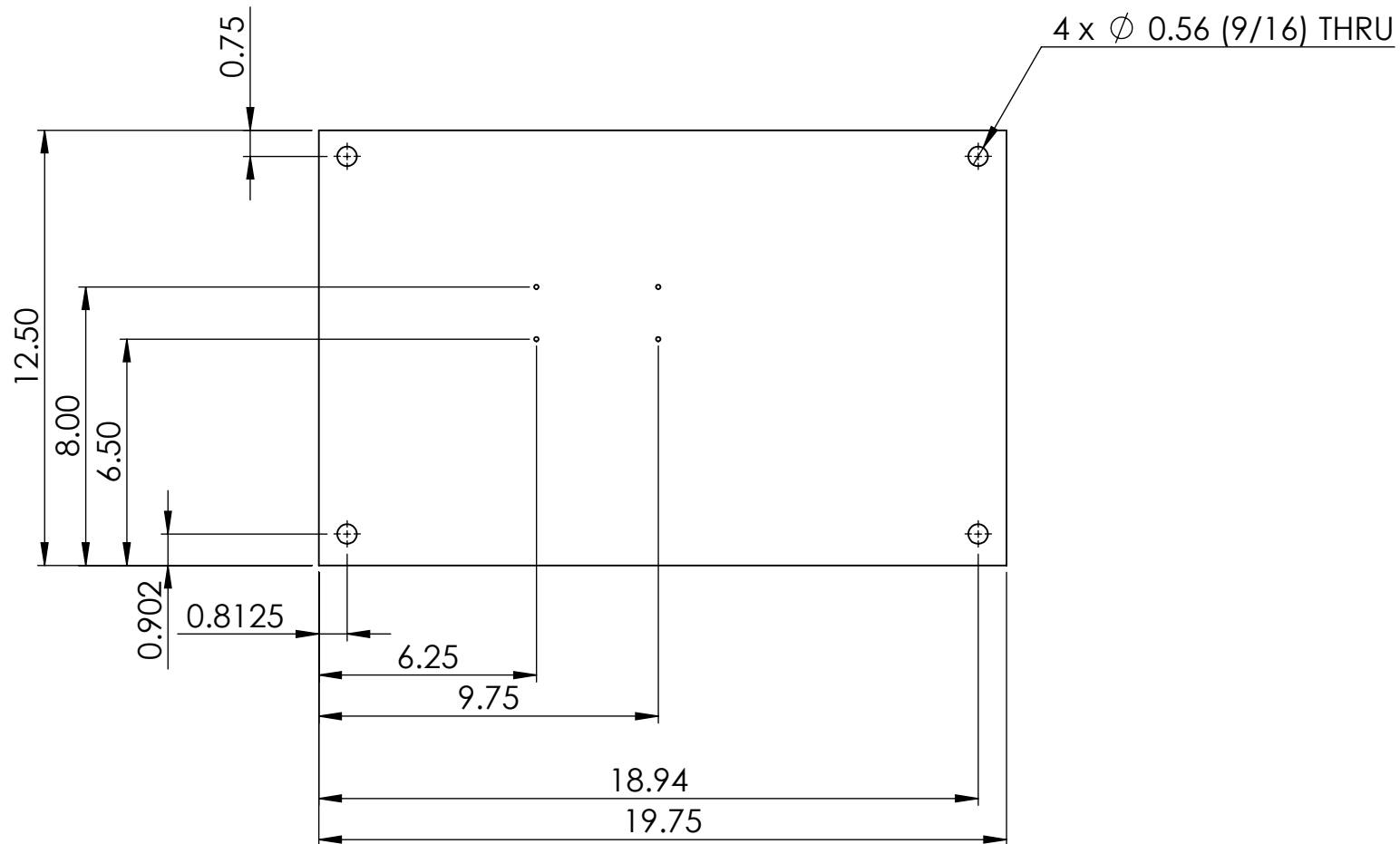
**UNIVERSITY OF IDAHO
ME DEPARTMENT**

PART #: C-3

QTY: 1

SCALE: 1:5

SHEET: 4 OF 10

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: 0.075" Steel

**DFIG
ENGINEERING**

**UNIVERSITY OF IDAHO
ME DEPARTMENT**

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: Bottom Plate

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 5/7/2013

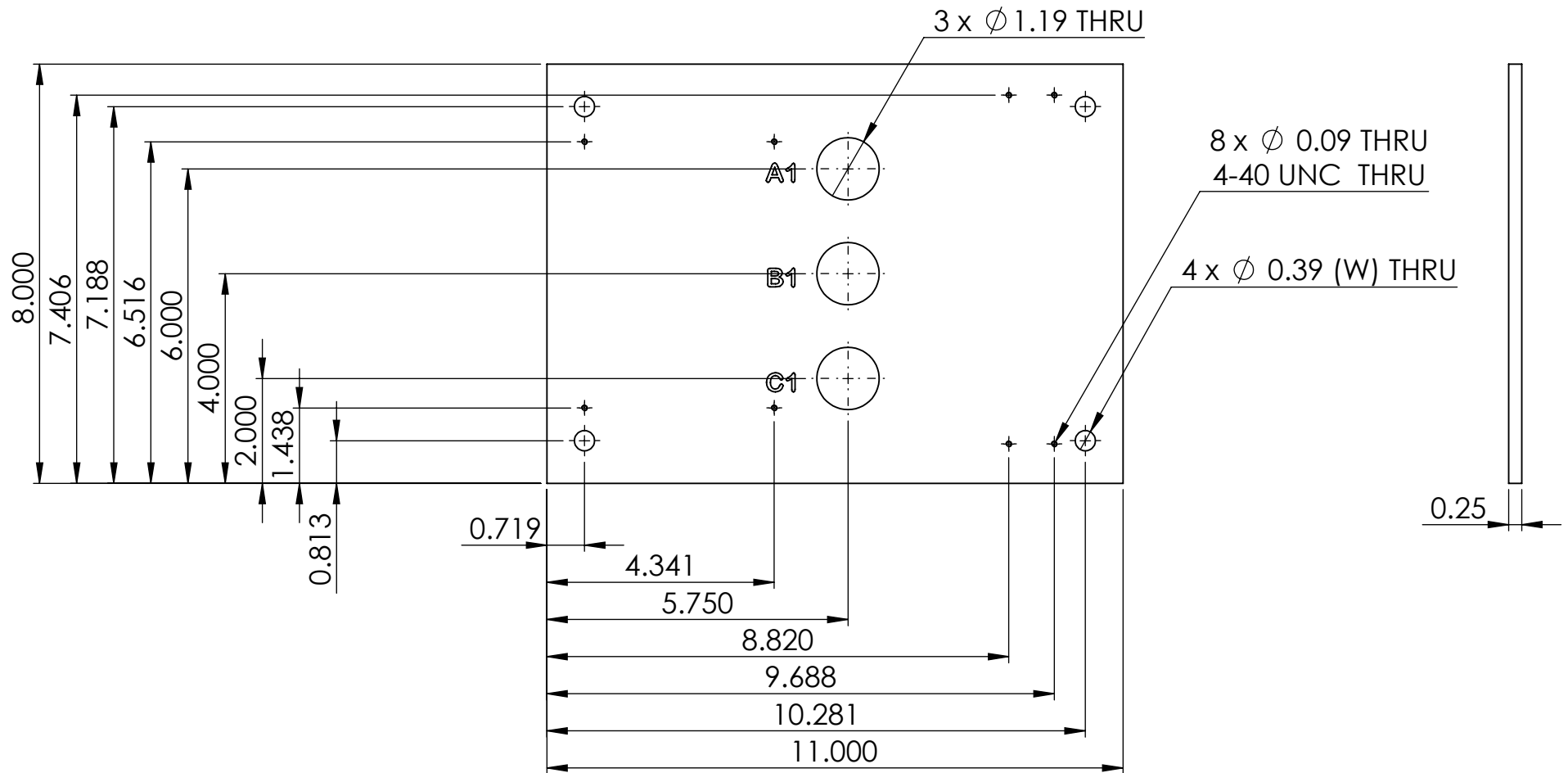
FILE NAME: Bottom Plate.SLDPRT

PART #: C-4

QTY: 1

SCALE: 1:5

SHEET: 5 OF 10

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION $\begin{smallmatrix} \text{---} \end{smallmatrix} \begin{smallmatrix} \text{---} \end{smallmatrix} \begin{smallmatrix} \text{---} \end{smallmatrix}$

MATERIAL: Plexiglas

**DFIG
ENGINEERING**

**UNIVERSITY OF IDAHO
ME DEPARTMENT**

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: Grid Side Connection Plate

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 3/28/2013

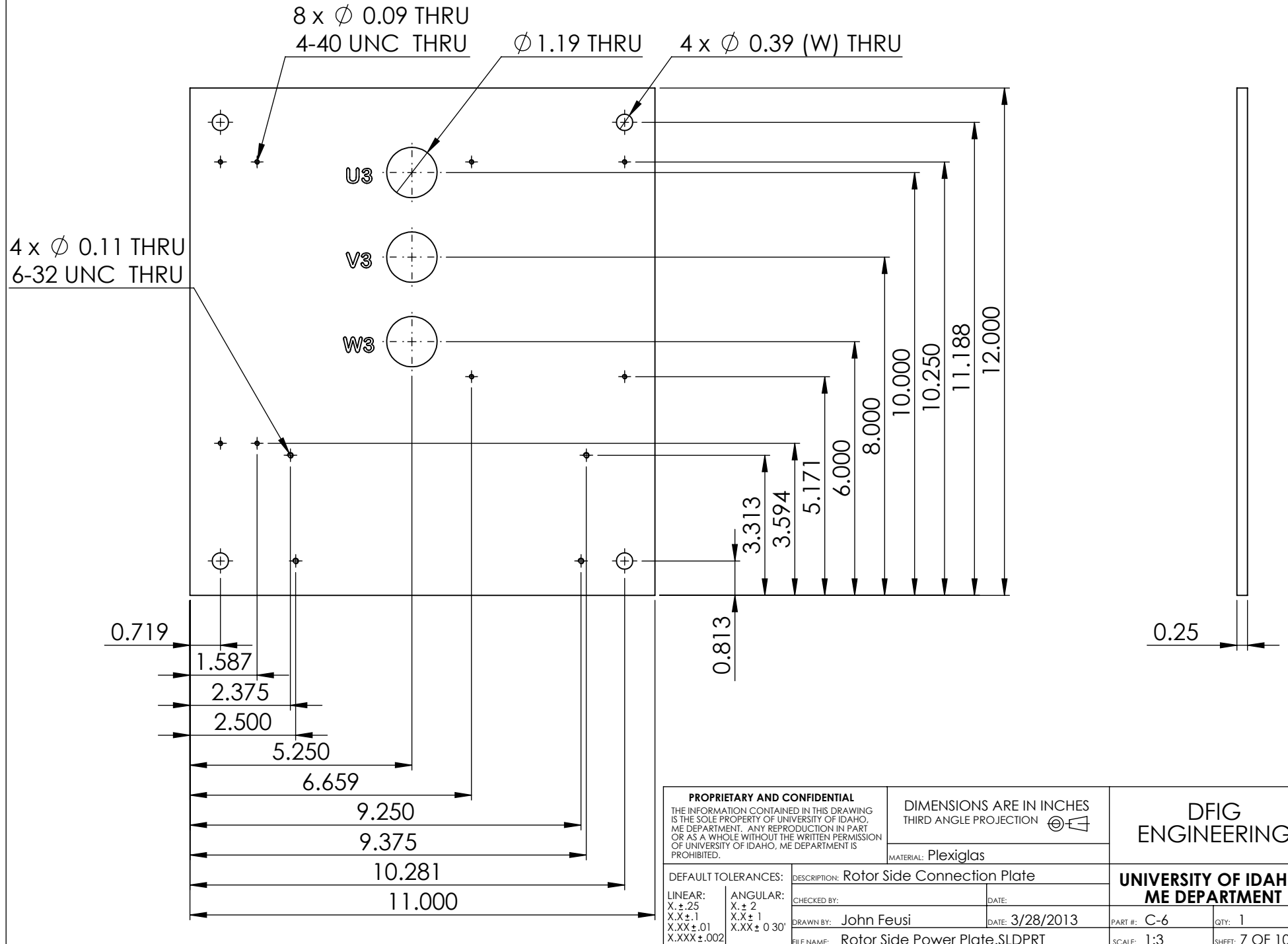
FILE NAME: Grid Side Power Plate.SLDPR

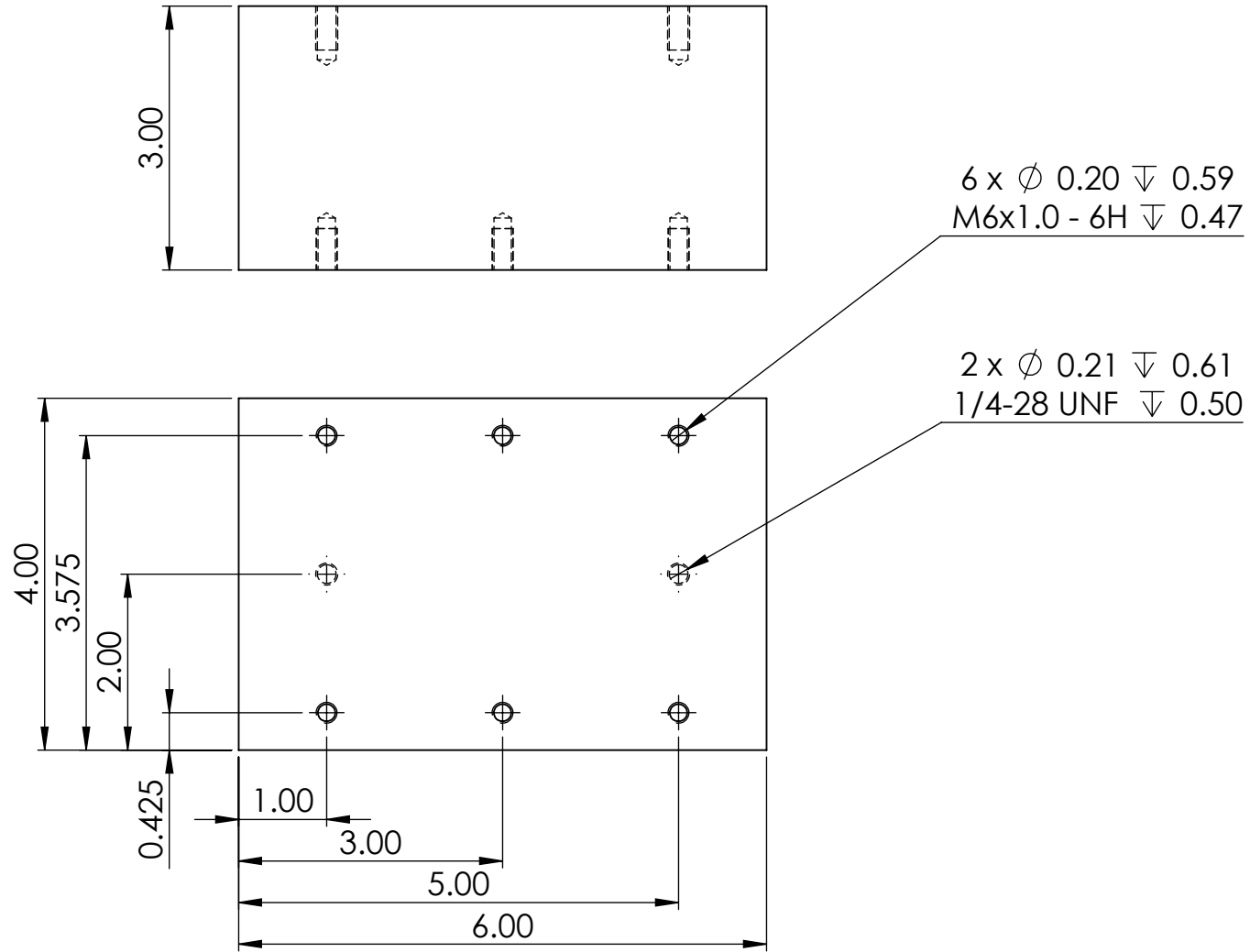
PART #: C-5

QTY: 1

SCALE: 1:3

SHEET: 6 OF 10



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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Steel

**DFIG
ENGINEERING**

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: 3x4x6 Block for SCR

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 3/6/2013

FILE NAME: 3x4x6 Steel Stock.SLDprt

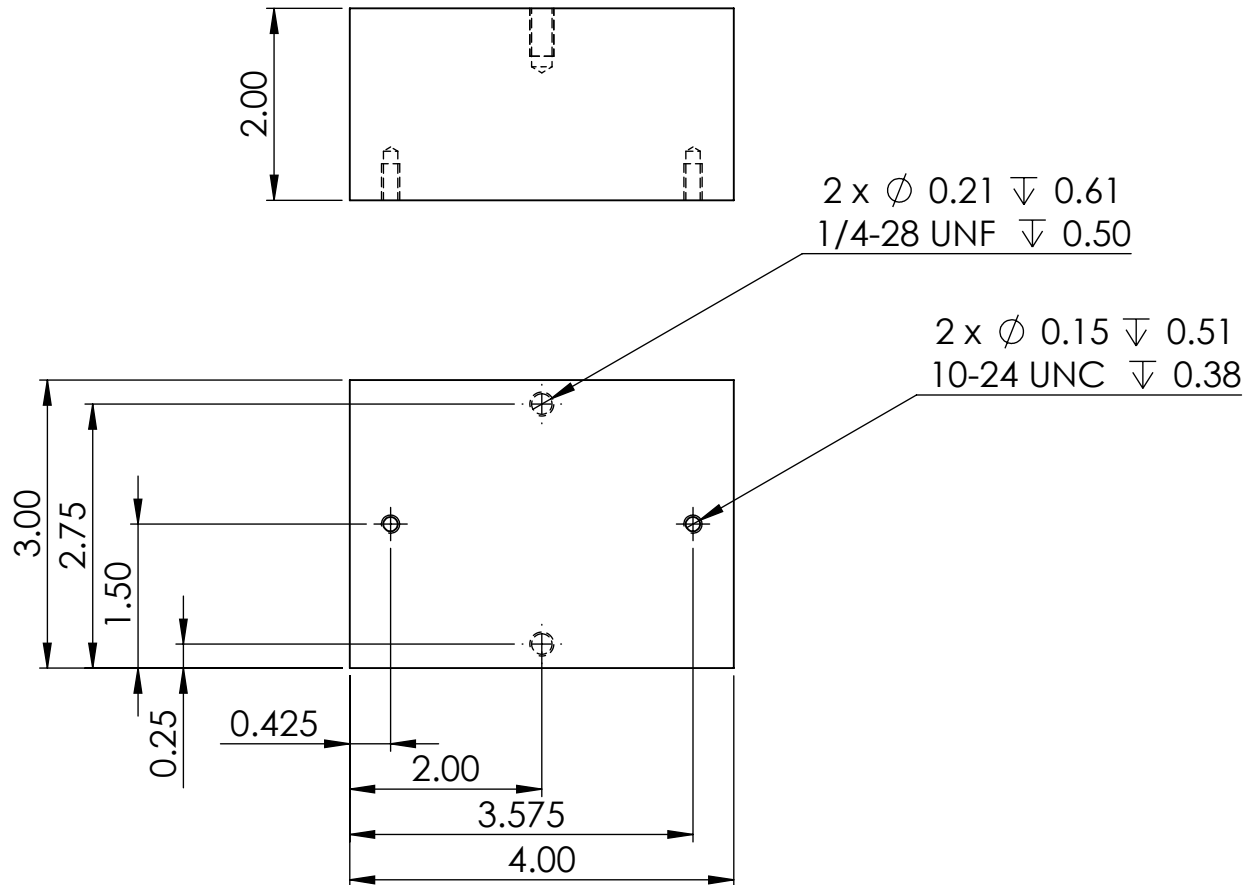
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ME DEPARTMENT**

PART #: C-7

QTY: 1

SCALE: 1:2

SHEET: 8 OF 10

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Steel

**DFIG
ENGINEERING**

DEFAULT TOLERANCES:

LINEAR:
X. \pm .25
X.X \pm .1
X.XX \pm .01
X.XXX \pm .002

ANGULAR:
X. \pm 2
X.X \pm 1
X.XX \pm 0 30'

DESCRIPTION: 3x4x2 Block for IGBT

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 4/1/2013

FILE NAME: 3x4x2 Steel Stock.SLDPRT

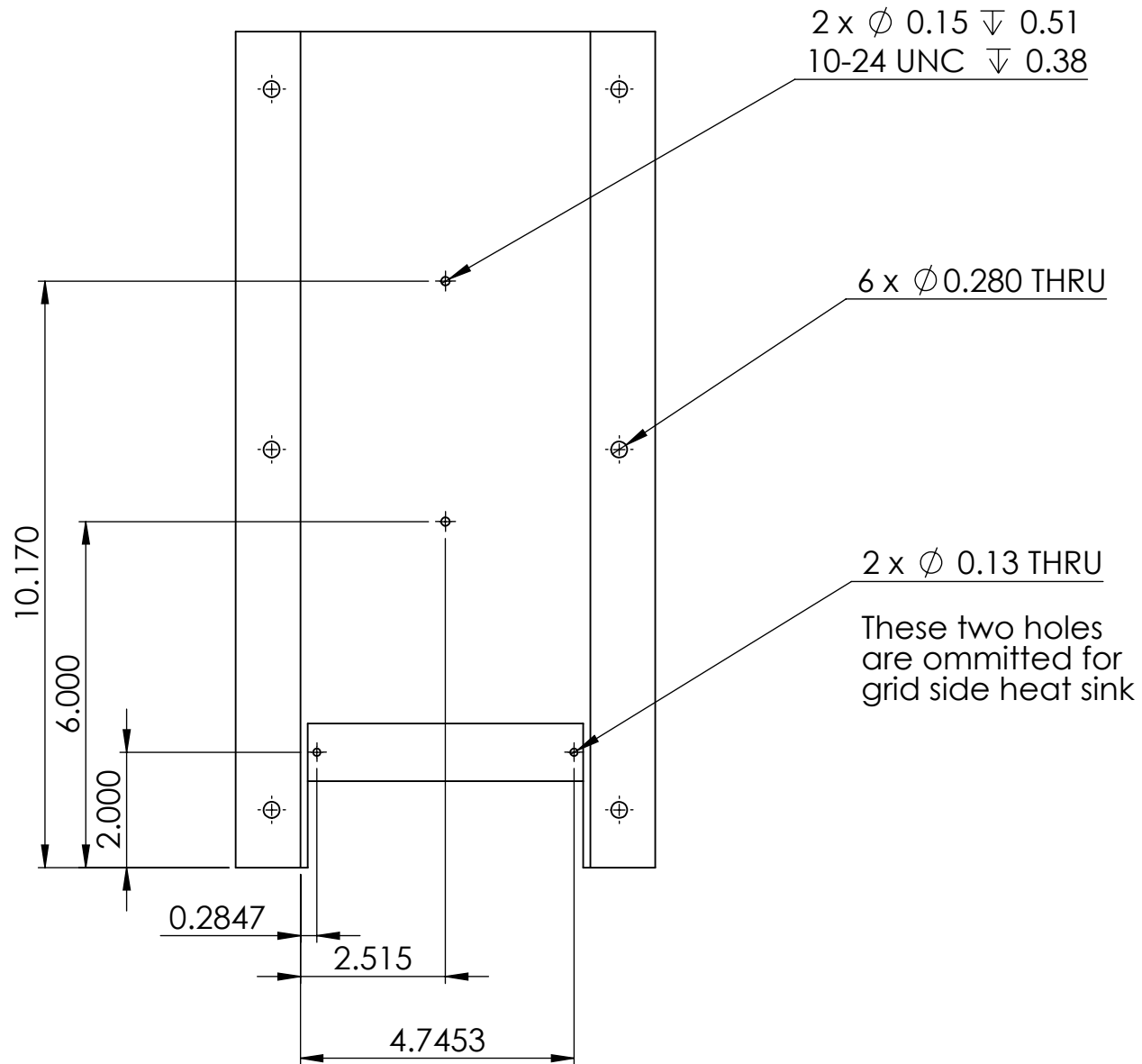
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ME DEPARTMENT**

PART #: C-8

QTY: 1

SCALE: 1:2

SHEET: 9 OF 10

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION 

MATERIAL: Extruded Aluminum

**DFIG
ENGINEERING**

**UNIVERSITY OF IDAHO
ME DEPARTMENT**

DEFAULT TOLERANCES:

LINEAR:
X. $\pm .25$
X.X $\pm .1$
X.XX $\pm .01$
X.XXX $\pm .002$

ANGULAR:
X. ± 2
X.X ± 1
X.XX $\pm 0.30'$

DESCRIPTION: Rotor Side Heat Sink

CHECKED BY:

DATE:

DRAWN BY: John Feusi

DATE: 5/7/2013

FILE NAME: Heat Sink CH5116.SLDPRT

PART #: C-9

QTY: 1

SCALE: 1:3

SHEET: 10 OF 10

